Survey Results of Green Sea Urchin (*Strongylocentrotus droebachiensis*) Populations in Queen Charlotte Strait, British Columbia, October 2008 and November 2010

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2012

SURVEY RESULTS OF GREEN SEA URCHIN (*Strongylocentrotus droebachiensis*) POPULATIONS IN QUEEN CHARLOTTE STRAIT, BRITISH COLUMBIA, OCTOBER 2008 and NOVEMBER 2010

by

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ABSTRACT

Waddell, B.J., and Perry, R.I. 2012. Survey results of green sea urchin (*Strongylocentrotus droebachiensis*) populations in Queen Charlotte Strait, British Columbia, October 2008 and November 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3000: ix + 73 p.

This report presents the results of two green sea urchin (*Strongylocentrotus droebachiensis*) surveys undertaken jointly between Fisheries and Oceans Canada (DFO) and industry (West Coast Green Urchin Association - WCGUA) in Queen Charlotte Strait, British Columbia, Canada, in October 2008 and November 2010. These surveys are part of a continuing series, starting in October 1995, whose long-term objectives are to assess variability in green sea urchin populations, and to monitor impacts due to a commercial fishery. The surveys were each conducted prior to the opening of the commercial green sea urchin fishing season, and were undertaken at three sites, which included areas open or closed to commercial fishing. The surveys were conducted by SCUBA divers, using the transect-quadrat method. Data were collected on size and abundance of green sea urchins, gonad weight and quality, and on the depth, substrate and vegetation; results are presented for three size classes of green sea urchins.

The mean densities and biomasses of legal-sized green urchins at the commercially fished site (the Stephenson Islets) have fluctuated over the series of surveys, but have generally increased over time. In October 2008, the mean densities and biomass estimates of all size classes increased from the previous survey (October 2006), and were the highest observed of all the surveys at this site for both legal-sized ($\geq$ 55 mm test diameter (TD)) and sublegal-mature (25 mm $\leq$ TD $<$ 55 mm) urchins, and second highest for immature (TD $<$ 25 mm) urchins. In addition, the mean legal-size and sublegal-mature-sized test diameters were the largest observed at this location, while the corresponding mean total wet weights were average to low. The size frequency distributions transformed at all three sites from a unimodal appearance in October 2006 to bimodal in October 2008 and remained bimodal in November 2010.

The mean legal and sublegal-mature densities and biomass estimates decreased at all three sites from October 2008 to November 2010 (except for the mean sublegal-mature density at Stubbs Island), but remained second highest ever observed at the Stephenson Islets. Some of the lowest mean legal and sublegal-mature gonad weights of the series of surveys were observed at all three sites in November 2010.

RÉSUMÉ

Waddell, B.J., and Perry, R.I. 2012. Survey results of green sea urchin (*Strongylocentrotus droebachiensis*) populations in Queen Charlotte Strait, British Columbia, October 2008 and November 2010. Can. Tech. Rep. Fish. Aquat. Sci. 3000: ix + 73 p.

Le présent rapport fait état des résultats de deux études sur l'oursin vert (*Strongylocentrotus droebachiensis*) réalisées conjointement par Pêches et Océans Canada (MPO) et l'industrie (West Coast Green Urchin Association - WCGUA), dans le détroit de la Reine-Charlotte, en Colombie-Britannique (Canada), en octobre 2008 et en novembre 2010. Ces études font partie d'une série ayant débuté en octobre 1995 et dont les objectifs à long terme consistent à évaluer les écarts dans les populations d'oursins verts et à surveiller les répercussions attribuables à la pêche commerciale. Ces études ont été réalisées avant le début de la saison de la pêche commerciale de l'oursin vert, dans trois différents sites incluant des zones ouvertes ou fermées à la pêche commerciale. Elles ont été réalisées par des plongeurs, selon la méthode des transects et des quadrats. Nous avons recueilli des données sur la taille et l'abondance des oursins verts, sur le poids et la qualité des gonades ainsi que sur la profondeur, les substrats et la végétation; les résultats sont présentés selon trois catégories de taille d'oursins verts.

La densité moyenne et la biomasse des oursins verts de taille réglementaire du site de pêche commerciale (îlots Stephenson) ont fluctué au cours de la série d'études mais, en règle générale, elles ont augmenté avec le temps. En octobre 2008, les estimations de la densité moyenne et de la biomasse de toutes les catégories de taille avaient augmenté par rapport à l'étude précédente (octobre 2006); elles affichaient les taux les plus élevés parmi toutes les études effectuées à ce site, tant pour les oursins de taille réglementaire (diamètre d'essai $\geq$ 55 mm) que ceux de taille inférieure-adulte (25 mm $\leq$ diamètre d'essai $<$ 55 mm) et les deuxièmes taux les plus élevés pour les oursins immatures (diamètre d'essai $<$ 25 mm). En outre, on a observé les diamètres d'essai moyens des oursins de taille réglementaire et de taille inférieure-adulte les plus élevés à cet endroit alors que le poids frais total moyen correspondant était moyen à faible. La distribution de la fréquence des tailles transformée aux trois sites était unimodale en octobre 2006, bimodale en octobre 2008 et bimodale en novembre 2010.

Les estimations de la densité moyenne et de la biomasse des oursins de taille réglementaire et de taille inférieure-adulte ont diminué entre octobre 2008 et novembre 2010, et ce, pour les trois sites (à l'exception de la densité moyenne des oursins de taille inférieure-adulte à Stubbs Island), mais elles affichaient toujours les deuxièmes taux les plus élevés jamais observés aux îlots Stephenson. On a observé certains des poids moyens de gonades d'oursins de taille réglementaire et de taille inférieure-adulte les plus faibles de la série d'études aux trois sites en novembre 2010.

INTRODUCTION

The commercial green sea urchin (*Strongylocentrotus droebachiensis*) fishery has existed in British Columbia since 1987. It is of modest value, but is an important component of the suite of dive fisheries in B.C. Hand-picking by divers is the only method allowed to harvest this species. It is managed using a minimum size limit of 55 mm test diameter (TD), by restricting areas and fishing seasons (originally open from November until March or April, but currently open from September to March or April), a limited entry licensing scheme, area quotas, and by an Individual Quota (IQ) system. Fishers are required, as a condition of licence, to complete harvest logbooks and charts and submit them to Fisheries and Oceans Canada (DFO). The logbooks contain information on the dates and locations that green urchins were caught, divers' names, how long fishing was conducted each day (i.e., effort), diving depths, and the total weight of urchins removed (i.e., catch). Up until 1996, these, along with sales slip data, were the only sources of data available upon which DFO stock assessments and management decisions for this fishery in B.C. were based. These data are of variable quality because of changes in fishing practices and the aggregating nature of green sea urchin distributions. The harvest logbooks also do not contain information on sublegal-sized urchins, size frequencies of the whole population, densities, roe quality and quantity, or habitat associations.

In order to obtain fishery-independent data, a scientific survey protocol was developed, with the long-term objectives of studying interannual variability, and to assess the impacts of the fishery on green sea urchin populations at a key fishery location. To meet these objectives, green sea urchin densities, size measurements, and samples for gonad quantity and quality were obtained, both in areas open and closed to commercial green sea urchin fishing, prior to the opening of the commercial fishery. All of the surveys have been conducted at the same location in Pacific Fisheries Management Area 12 (or PFMA 12 or Area 12, where the majority of the fishery occurs), in Queen Charlotte Strait, near Telegraph Cove (Figs. 1a-1c). The Stephenson Islets met the criterion for the survey site open to commercial fishing because fishers have historically found this site to have consistently high numbers of legal-sized green sea urchins. Stubbs Island and the Plumper Islands met the criterion for monitoring population changes due to environmental variations, and are located close to the Stephenson Islets. Stubbs Island and the NW section of the Plumper Islands have been closed to commercial fishing (for research purposes) since the fall of 1995.

The first three initial years of these surveys (from fall 1995 to spring 1998; Waddell *et al.* 1997, 2002, 2003), were conducted just prior to the opening of the green sea urchin commercial fishery (which was usually in mid-November), and again in the spring, immediately following the closure of the fishery (which was usually in mid-March). (Note that since a fishing season runs from the fall of one year to the spring of the next, the nomenclature for a fishing season is "the 4 numbers of the fall year" / "the last 2 numbers of the spring year", e.g. 2008/09). Due to funding shortages and generally inclement weather in the spring, surveys carried out following the annual closure of the

fishing season were discontinued after March 1998. However, surveys were continued annually, every fall from November 1998 to November 2004 (Waddell and Perry 2005, 2006). Funding shortages again prevented the survey from being conducted in the fall of 2005, therefore the series of surveys were conducted every second fall, starting in October 2006 (Waddell and Perry 2007). Following this bi-annual survey sequence, this current report presents the data collected from two cooperative surveys performed by DFO and industry (West Coast Green Urchin Association; WCGUA) in October 2008 and November 2010. In every case, surveys were undertaken just prior to the opening of the commercial green sea urchin fishery in the area. Although the commercial fishery has been opening in September since 2008, the survey area and surrounding areas remain closed to fishing until surveying has been completed for the season. These recent surveys continued to be conducted at the end of October or early November so that the results remained comparable to past surveys.

By coordinating surveys that involved all parties with interests in the green sea urchin fishery, i.e., DFO, First Nations (first two years of surveys) and the commercial industry, there has been improved confidence and acceptance of these data. All of the data are also used in the stock assessments for this species. An overview and interpretation of all of the surveys conducted at this location will be presented in a future paper. Information on the historical trends of this stock and its fishery in British Columbia is available in Perry *et al.* (2002). In addition, detailed information on the management of the green urchin fishery in British Columbia is available from its Integrated Fishery Management Plan (DFO 2011).

METHODS

(a) DATA COLLECTION – FIELD AND LAB

The two surveys were performed October 18-19, 2008, and November 8 and 10, 2010. It was designed, organized, conducted, and supervised by DFO. Industry divers were hired on contract to work alongside DFO divers. There were two dive teams (i.e., two boats), each with one industry and one DFO diver, one boat driver (industry or DFO), one dive tender (industry or DFO), and one observer/recorder (DFO). The vessels involved were the CFVs '*Emma III*' and the '*CCC*', both owned by an industry fisher, and the DFO vessel '*Pallasi*'. During both surveys, there were eight transects surveyed for green sea urchins in the Stephenson Islets (50°34.5' N, 126°49.5' W), at the north end of Johnstone Strait, near Telegraph Cove and Weynton Passage (Fig. 1b), three transects at nearby Stubbs Island (50°36.2' N, 126°49.2' W; Fig. 1c), and four transects in the Plumper Islands (50°34.6' N, 126°48.0' W; Fig. 1c). In the past, there have been as many as ten transects surveyed at the Stephenson Islets, four transects at Stubbs Island, and six transects in the Plumper Islands. The dive teams attempted to survey all of the same transects as in the 14 previous surveys, however, strong currents and large numbers of sea lions prevented the whole suite of transects from being surveyed during the short time available.

The transect positions were randomly selected during the first survey in 1995 and marked on a chart prior to arriving at the survey area (Waddell *et al.* 1997, 2002). The transects run perpendicular to the shoreline and/or depth contours (with slight adjustments of the angle to best manage the direction of the current), starting at 10.0 m (32.8 ft) below Chart Datum (CD) and continuing up to zero CD. A computer program called "Tides and Currents for Windows" (Nautical Software Inc. 1995) was used to calculate the tide levels for every five minutes so that the depth to CD could be determined before each dive commenced. A weighted (lead) line was laid from shallow to deep to mark the transect, with a surface marker buoy indicating each end of the line. Beginning at the deep end, the divers placed a 1 m^2 aluminum quadrat on the substrate beside the lead line and measured the test diameter (TD) (using calipers) of all green sea urchins within the quadrat, and counted all red (*Strongylocentrotus franciscanus*) and purple (*S. purpuratus*) sea urchins. All urchins were removed from the quadrat as they were being measured to avoid repeating measurements. An urchin was considered to be in a quadrat if one-half or more of its body was within the quadrat's boundaries. Sometimes green urchins were under vegetation, rocks, or in crevices, so all surfaces were explored in order to find all sea urchins. One diver did all of the measuring while the other diver recorded the data on waterproof paper. The depth, substrate and type of vegetation were also recorded for each quadrat, and then the quadrat frame was rolled over in the direction of the lead line, and the procedure was repeated along the full length of the transect. Initially, every quadrat was fully surveyed (all green urchins measured) in all transects of the survey area. However, since October 2002, due to the increasing densities (and time restraints), measurements of green urchins were taken in every second quadrat in the Stephenson Islets, alternating with counts of green urchins in those quadrats not measured. All green urchins continued to be measured in every quadrat at Stubbs Island and the Plumper Islands.

The surface personnel recorded the position (using a GPS) for both the start and finish of the transects, as well as the divers' start and finish times for each transect (for use in calculating depth from CD), and the weather conditions.

Three green sea urchins of each of three size classes (small, medium and large) were randomly collected along the transect lines during the surveys for later laboratory analyses of size and weight and dissected to obtain roe quality information. In addition, another 10 urchins were randomly collected along the transect line for size and weight information only (i.e., not dissected). These latter samples were all measured on the same day as they were collected, whereas all of the other urchins were measured and dissected on the day following collection. For each of the dissected urchins, the following data were recorded: test diameter; test height; total wet weight (whole weight); drained weight (cracked open, turned over and left to drain for a few minutes); gutted weight (drained, with stomach and contents removed, but gonads included); gonad weight; gonad colour; gonad texture; and sex. Gonad colour was given a qualitative rating code of 0 (unknown (i.e., lost), or no gonad present), 1 (orange/yellow), 2 (yellow with other colours), or 3 (brown/red). Gonad texture was also given a qualitative rating code of 0 (unknown (i.e., lost), or no gonad present), 1 (firm), 2 (semi-firm), and 3 (flimsy).

Data collected from all green sea urchin independent surveys are stored in a database in DFO's Shellfish Data Unit (SDU) at the Pacific Biological Station in Nanaimo, B.C., Canada.

(b) DATA ANALYSES

Occasionally divers started surveying deeper than 10 m below CD, or they continued surveying shallower than 0 m CD. Since the area estimate for the Stephenson Islets is based on the area between the 0 and 10 m isobaths, and green urchins are usually sparse at depths greater than 10 m below CD, the divers' data were truncated to include only data collected between 0 and 10 m (33 ft) below CD for the overall density calculations, biomass, and for the density by substrate calculations. The original (unadjusted) data were used for all other calculations presented in this report.

Test diameter frequency distributions were analyzed using the computer software "MIX3aa" (Macdonald 1994) to identify dominant size modes under the assumption that individual modes were normally distributed (see Macdonald and Pitcher (1979), and Macdonald and Green (1988), for details). In general, initial parameters (mean and standard deviation) were assigned by examination of test diameter frequency data distributions collected during the surveys at each site. The software "MIX3aa" was then used to estimate the proportions while keeping the mean and standard deviation parameters fixed. Next, estimates of mean, standard deviation, and proportion were calculated by varying the constraints on each until a reasonable fit to the data was established. This fit was determined by the goodness-of-fit chi-square statistical test and examination of the size frequency histogram with its fitted components. The software fit the means, proportions, and standard deviations of the size frequency distributions using the Quasi-Newton Algorithm technique (Macdonald and Green 1988). The test diameter frequency distributions were analyzed for data obtained at Stephenson Islets, Stubbs Island, and Plumper Islands.

In many of the analyses, the data have been separated into three different size classes: legal-sized (TD $\geq$ 55 mm); sublegal-mature (25 mm $\leq$ TD $<$ 55 mm); and sublegal-immature (or immature; TD $<$ 25 mm). The mature/immature size of 25 mm TD was approximated from previous dissection roe quality and maturity data (Waddell *et al.* 2002), in which 100% of green urchins $<$ 25 mm were immature (no gonad present) compared with 6% of urchins $\geq$ 25 mm being immature.

Mean and total densities of green urchins for each transect within each of the three survey sites (Stephenson Islets, Stubbs Island, and Plumper Island) were calculated as described by Jamieson and Schwarz (1998). These surveys are characterized by the quadrats within a transect not being independent (e.g. if one quadrat has a high number of urchins, then adjacent quadrats are likely to have high numbers as well), transect lengths vary among the transects, and all urchins within each transect are counted. These features indicate a "complete cluster" sampling design with unequal-sized clusters (Jamieson and

Schwarz 1998). The appropriate calculation for the mean density (of a particular size class of urchins) is:

$$\overline{D} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} L_i} \qquad (1)$$

and for the standard error of density is:

$$SE(\overline{D}) = \sqrt{\frac{1}{\overline{L}^2}\frac{1}{n}\frac{\sum (U_i - L_i\overline{D})^2}{n-1}} \qquad (2)$$

with n = the number of transects sampled in a particular site;

U_i = the total number of urchins of the appropriate size class in transect i, $i = 1,2,...,n$;

L_i = the total number of quadrats in transect i; and

$\overline{L}$ = $\frac{1}{n}\sum_{i=1}^{n} L_i$, the average area of the transects in the site.

Since the area of a quadrat was 1 m^2, L_i is also equal to the area of the transect.

In the results that follow, standard errors have not been calculated for the individual transects since the transect has been defined as the (cluster) sample unit, and therefore the (n-1) term in the denominator of the equation for the standard error goes to zero. In the calculation of urchin densities by depth range and substrate type, however, the quadrats have been considered as the sampling unit, and distributed among the various depth and substrate categories. This reduces (but does not entirely eliminate) the problem of non-independence among adjacent quadrats, and so standard errors about the mean densities for these classifications have been calculated using standard formulae (e.g. as found in Sokal and Rohlf (1981) and as implemented in the "EXCEL 2002" (Microsoft) statistical software package).

When calculating the "densities of green urchins by depth range", the actual depth below CD had to be determined for each quadrat, which depended on the continually changing tide height. The method for calculating this has changed slightly over the years. Initially (Waddell *et al.* 1997, 2002, 2003), the mean tide height above CD over a transect was calculated and then this one mean value was subtracted from all of the depth gauge readings for that transect. It was then realized that sometimes the tide could change significantly over the length of a dive, especially if it took a long time to survey a whole transect. The method was changed (Waddell and Perry 2005, 2006) by first calculating the number of minutes spent at each tide height above CD (rounded feet) over the length of each transect, using the "Tides and Currents for Windows" program (Nautical Software Inc. 1995) set for one minute intervals. Then the tide height above CD was calculated for each quadrat by proportioning the dive time over the whole transect according to the number of quadrats in each transect. Once this was calculated, then the tide height above CD was subtracted from the depth gauge reading recorded for each quadrat, to give the approximate adjusted depth below CD. However, some quadrats

could take longer than others to survey, especially ones that had high densities of urchins, and so the method was modified further (Waddell and Perry 2007). Therefore, instead of proportioning the number of quadrats over the dive time at each tide height, we calculated the mean number of urchins measured per minute, and how much time was spent at each tide height. The numbers of urchins were then calculated for each tide height. By going through the datasheets and counting the number of urchins, we were able to estimate more accurately when (at which quadrat) the tide height would have changed. The tide height above CD was subtracted from the depth gauge reading for each quadrat, to give the approximate adjusted depth below CD. Note that the depth readings are initially recorded in feet and then converted to meters for the report because the depth gauges only read in feet.

The three most abundant substrates in each quadrat were recorded, in order of prominence. The tables and figures in this report that display the substrate data use three digit codes that represent the order of prominence and type of substrates observed. A similar recording method was used for vegetation types. However, there are some problems associated with these latter data, making it difficult to interpret the results. Therefore, although vegetation data were recorded, they are not presented in this report.

The statistical software package "EXCEL 2002" (Microsoft) was used to find the best relationships (i.e. highest R^2) between TD (in millimeters) and the variables test height (in millimeters), total wet weight (in grams), and gonad weight (in grams). These were calculated from dissection data for all sites combined, and for each of the three sites separately, for both of the surveys. The majority of the calculations had the best fit when the power equation was used (i.e., $variable = \alpha(TD)^{\beta}$), therefore this was the standard equation used for all calculations. Note that samples that had gonad weights of zero were removed from the calculations.

The mean abundance of green urchins was converted to total biomass for all of the survey sites using the mean individual urchin weights (total wet weights, separated into three size classes), the mean densities, and the total area of each site. Rather than using a single mean individual weight for the whole sample population to convert abundance to biomass (as in Waddell *et al.* 1997), we used the following method (as in Waddell *et al.* 2002, 2003, and in Waddell and Perry 2005, 2006, 2007). TD-weight relationships were derived separately for each of the three survey sites using the laboratory measurements. These were then applied to each individual urchin measured in the field survey, in each of the three sites accordingly, to calculate the individual weights. The measured green urchins were separated into three size classes: legal-sized ($TD \geq 55$ mm); sublegal-mature ($25 \text{ mm} \leq TD < 55$ mm); and immature ($TD < 25$ mm). Then the mean individual urchin (total wet) weight ($\overline{W}_j$) was calculated for each size class (j). The standard error about the mean weight for each size class ($SE(\overline{W}_j)$) was determined by calculating the standard deviation of the mean weight and dividing by the square root of the sample size.

The total biomass for a particular site was then calculated as

$$B = \sum_{j=1}^{3} \overline{D}_j (\overline{W}_j)(A) \tag{3}$$

where j subscripts the three size classes. The criterion used to estimate "total area" (A) of green sea urchin habitat was "all area with a depth between 0 and 10.0 m below CD". The area was estimated as 485,200 m^2 for Stephenson Islets, 19,600 m^2 for Stubbs Island, and 223,600 m^2 for the Plumper Islands, based on a geographic information program called COMPUGRID (Geo-Spatial Systems Ltd. 1996).

The standard error of the total biomass for a particular site, which includes the uncertainties in the mean density and mean weight by size category, was calculated as:

$$SE(B) = \left[\sum_{j=1}^{3} \left[\left(\left(\frac{SE(D)_j}{\overline{D}_j} \right)^2 + \left(\frac{SE(W)_j}{\overline{W}_j} \right)^2 \right)^{\frac{1}{2}} (B_j) \right]^2 \right]^{\frac{1}{2}}, \tag{4}$$

with symbols as previously defined, and assuming that the area (A) (used within the calculation for B_j) is known without error. A further assumption is that the errors in mean density and mean weight, and among size classes, are independent and random.

In order to determine the impact of fishing on the stock of green sea urchins at Stephenson Islets (the commercial fishing site), we calculated exploitation by the fishing industry using the following equation:

$$Expl = \frac{B_{fishing}}{B_{Nov}}, \tag{5}$$

with standard error defined by:

$$SE(Expl) = (Expl) \left[\left(\frac{SE(B_{fishing})}{B_{fishing}} \right)^2 + \left(\frac{SE(B_{Nov})}{B_{Nov}} \right)^2 \right]^{\frac{1}{2}}. \tag{6}$$

$B_{fishing}$ is the biomass removed from the Stephenson Islets by fishing, with standard error $SE(B_{fishing})$; B_{Nov} is the pre-fishery (November) biomass at the Stephenson Islets, with standard error $SE(B_{Nov})$, defined here as either the total biomass or the biomass of legal-sized urchins from the fall surveys, and $Expl$ is the exploitation of green urchins (with standard error $SE(Expl)$), defined as a proportion of the pre-fishery biomass (either total or legal-sized only). The biomass removed by the fishery ($B_{fishing}$) at Stephenson Islets was determined by examining dockside validation records and charts of fishing locations submitted with these records, and tabulating the total landings. The precise error of the dockside weight measurements for validation is unknown, but considered to be small, therefore $SE(B_{fishing})$ was set at 1% of $B_{fishing}$.

Note that EXCEL spreadsheets are used for many of these calculations, and that each result from a sequence of calculations is not rounded off. Therefore, any differences between calculations and values shown in the tables are due to rounding errors.

Green urchin densities increased over the years of the surveys, until it became difficult to measure all urchins within the time and budget constraints, and it became necessary to change the methodology. On some transect lines, (i.e., the Stephenson Islets, because it has the highest number of transects), instead of measuring all green urchins in every quadrat, they were measured in every second quadrat and urchins in the alternate quadrats were counted only. These unmeasured urchins (or "unknowns") were incorporated into the data analyses. The estimates of legal and sublegal urchins within the unmeasured urchins were calculated using the proportions of measured legal-sized and sublegal-sized urchins of all the measured urchins. These values were then added to the number of measured legal-sized and sublegal-sized urchins to calculate the total numbers of each of these size classes. These adjustments of the data to include unmeasured urchins in the data analyses were done for many of the tables, including density by transect and site, density by depth range, and the biomass estimates.

RESULTS

(a) OCTOBER 18-19, 2008 SURVEY

Eight transect lines were surveyed in the Stephenson Islets (Table 1, Fig. 1b; missing Transects 7 and 11 this survey), three transects were surveyed at Stubbs Island (Fig. 1c; missing Transect 16), and four transects in the Plumper Islands (Fig. 1c). Some transects were missed due to strong currents and lack of time. A population of Stellar sea lions (*Eumetopias jubatus*; approximately 50 animals or more) continued to interfere with surveying at Stubbs Island.

Size: A total of 437 quadrats were completed in this survey, of which 311 quadrats were measured (Table 2). Test diameter (TD's) measurements were taken for 2,085 urchins and another 1,788 urchins were counted. The data for the unmeasured urchins were distributed between the three size classes, as described in the Data Analyses section. This adjustment revealed that of the total 3,873 green urchins observed in this survey, 1,540 (39.8%) were of legal size, 2,076 (53.6%) were sublegal-mature, and 257 (6.6%) were sublegal-immature (Table 2). Figure 2a shows the size frequency distribution for all the sites combined during the October 2008 survey. When combining all the test diameters measured at all sites during the survey, two distinct modes best fit the distribution ($X^2 = 82.1$; df = 34; $p < 0.0001$), with mean test diameters of 26 and 55 mm (Table 3). Mean TDs and weights for urchins from all sites combined were 62.6 ± 0.2 mm and 76.9 ± 0.6 g for legal-sized urchins, 43.7 ± 0.2 mm and 29.9 ± 0.4 g for sublegal-mature urchins, and 19.8 ± 0.3 mm and 3.2 ± 0.1 g for sublegal-immature urchins (Table 4).

Density: The mean overall total density during this survey (all sites combined) was 8.85 ± 1.80 urchins/m^2 (Table 5). After adjusting for unmeasured urchins, the mean overall densities were 3.52 ± 0.58 urchins/m^2 for legal-sized urchins, 4.74 ± 1.38 urchins/m^2 for sublegal-mature urchins, and 0.59 ± 0.13 urchins/m^2 for sublegal-immature urchins.

Depth: The sample mean densities of green sea urchins by depth range for all sites combined in October 2008 are shown in Table 6a and Fig. 3a. The data for unmeasured urchins were proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns. The highest mean total density of green urchins for all sites combined (18.74 ± 2.28 urchins/m^2) was observed in the 0.3 to 1.5 m (1 to 5 ft) below CD range. This depth range also contained the highest density of sublegal-sized urchins (9.15 urchins/m^2), whereas the highest density of legal-sized green urchins (10.26 urchins/m^2) was observed one depth range shallower, at 1.2 to 0.0 m (4 to 0 ft) above CD. As observed in past surveys, the mean total densities generally decreased continuously with each deeper depth interval, with the exception of the deepest depth interval surveyed (11.0 to 12.2 m or 36 to 40 ft below CD), which increased in density (10.00 urchins/m^2; n=1). The lowest total density (3.17 ± 0.70 urchins/m^2) of green sea urchins occurred in the 9.4 to 10.7 m (31 to 35 ft) below CD depth range.

Substrate: Fig. 4a shows the mean densities of green sea urchins by primary substrate type for all sites combined. Smooth bedrock was the most sampled substrate (221 quadrats), with a total density of 9.69 ± 0.83 urchins/m^2 (Table 7a), but the highest total density (12.62 ± 1.39 urchins/m^2, 98 quadrats) was observed on creviced bedrock.

(i) Stephenson Islets

Size: There were 149 quadrats in which green urchins were measured (1,450 green urchins) and 126 quadrats in which green urchins were only counted (1,788 green urchins), for a total of 275 quadrats surveyed (total 3,238 green urchins) at the Stephenson Islets (Table 2). After adjusting for unmeasured urchins, there were 1,181 (36.5%) legal-sized, 1,851 (57.2%) sublegal-mature-sized, and 207 (6.4%) sublegal-immature-sized urchins. The size frequency distribution for the October 2008 survey is shown in Fig. 2b, and the test diameter frequency analysis is presented in Table 3. Stephenson Islets had two dominant size modes at 25 and 53 mm TD ($X^2 = 58.8$; df = 31; p = 0.0019). Mean TD's and weights for urchins from Stephenson Islets were 62.1 ± 0.2 mm and 74.0 ± 0.8 g for legal-sized urchins, 44.3 ± 0.3 mm and 30.4 ± 0.4 g for sublegal-mature urchins, and 19.9 ± 0.4 mm and 3.2 ± 0.1 g for sublegal-immature urchins (Table 4).

Density: After adjusting for the unmeasured urchins, the mean total, legal, sublegal-mature and sublegal-immature densities at the Stephenson Islets were 11.75 ± 1.87 urchins/m^2, 4.29 ± 0.57 urchins/m^2, 6.71 ± 1.71 urchins/m^2, and 0.75 ± 0.16 urchins/m^2, respectively (Table 5). The highest total (17.64 urchins/m^2), sublegal-mature (13.54 urchins/m^2), and sublegal-immature-sized (1.34 urchins/m^2) densities occurred at Transect 9 (Table 5), while the highest densities of legal-sized (6.47 urchins/m^2) green urchins were observed at nearby Transect 13.

Depth: The highest mean total (23.71 ± 2.98 urchins/m^2) and sublegal-sized (13.29 urchins/m^2) green urchin densities all occurred in the 0.3 to 1.5 m (1.0 to 5.0 ft)

below CD depth range (42 quadrats; Table 6b; Fig. 3b), whereas the highest legal-sized density (11.41 urchins/m^2) occurred in one depth range shallower (1.2 to 0.0 m or 4.0 to 0.0 ft above CD, 32 quadrats). Densities generally decreased with depth.

Substrate: The most frequently surveyed substrate was smooth bedrock (128 quadrats, with a total density of 13.13 ± 1.25 urchins/m^2; Table 7b and Fig. 4b), but the highest total densities (14.30 ± 5.30 and 14.07 ± 1.56 urchins/ m^2) were observed on boulder (10 quadrats) and creviced bedrock (84 quadrats), respectively.

(ii) Stubbs Island

Size: Green urchins were measured in all 49 quadrats surveyed at Stubbs Island, totaling 373 measurements (Table 2). There were 237 (63.5%) legal-sized, 117 (31.4%) sublegal-mature, and 19 (5.1%) sublegal-immature urchins. The analysis of the size frequency distribution (Table 3 and Fig. 2c) showed that there were two main frequency modes at 23 and 58 mm TD, but did not fit the model well (X^2 = 30.9; df = 31; p = 0.4724). Mean TD's and weights of urchins at Stubbs Island in October 2008 were: 62.9 ± 0.3 mm and 87.0 ± 1.3 g for legal-sized urchins; 45.6 ± 0.7 mm and 37.1 ± 1.2 g for sublegal-mature urchins; and 19.0 ± 0.8 mm and 3.2 ± 0.3 g for sublegal-immature urchins (Table 4).

Density: Transect 16 was not surveyed during this survey. The mean overall total, legal, sublegal-mature and sublegal-immature densities of the three transects surveyed at Stubbs Island were 7.61 ± 3.38 urchins/m^2, 4.84 ± 1.93 urchins/m^2, 2.39 ± 1.33 urchins/m^2, and 0.39 ± 0.14 urchins/m^2, respectively (Table 5). The highest total, legal-sized, sublegal-mature, and sublegal-immature urchins (14.31, 8.63, 5.06, and 0.63 urchins/m^2, respectively), were all observed at Transect 15.

Depth: The highest mean total (21.50 ± 5.35 urchins/m^2), legal (14.67 urchins/m^2), and sublegal (6.83 urchins/m^2) densities all occurred in the shallowest depth range surveyed (the 1.2 to 0.0 m (4 to 0 ft) above CD depth range; Table 6c; Fig. 3c).

Substrate: The substrate most frequently surveyed at Stubbs Island was smooth bedrock (45 quadrats, with a total density of 7.76 ± 1.36 urchins/m^2; Table 7c). Cobble was the primary (main) substrate with the highest mean overall total density (8.50 urchins/m^2), but only 2 quadrats of this substrate were surveyed, so the S.E. was considerably large (± 7.50 urchins/m^2; Table 7c and Fig. 4c).

(iii) Plumper Islands

Size: Green sea urchins were measured in all 113 quadrats surveyed at the Plumper Islands, totaling 261 measurements (Table 2). There were 122 (46.7%) legal-sized urchins, 108 (41.4%) sublegal-mature urchins, and 31 (11.9%) sublegal-immature urchins (Table 2). The size frequency distribution for the Plumper Islands is presented in Fig. 2d, and Table 3 presents the results of the test diameter frequency analysis. The best fit for the model was two very distinct frequency modes, located at 29 and 62 mm (X^2 = 45.7; df = 34; p = 0.0863). The mean TD's and weights for legal, sublegal-mature and

immature-sized urchins were 64.3 ± 0.5 mm and 88.9 ± 2.1 g, 36.2 ± 0.8 mm and 20.1 ± 1.2 g, and 20.1 ± 0.7 mm and 3.7 ± 0.3 g, respectively (Table 4).

Density: The mean densities at the Plumper Islands in October 2008 (after adjusting for unmeasured urchins) were 2.31 ± 0.68 urchins/m^2 for all size categories combined (total), 1.08 ± 0.52 urchins/m^2 for legal-sized urchins, 0.96 ± 0.18 urchins/m^2 for sublegal-mature urchins, and 0.27 ± 0.11 urchins/m^2 for sublegal-immature urchins (Table 5). The highest mean total (4.04 urchins/m^2), legal-sized (2.43 urchins/m^2), and sublegal-immature (0.57 urchins/m^2) densities occurred at Transect 22. The highest mean sublegal-mature-sized green urchin densities (1.55 urchins/m^2) occurred at Transect 23.

Depth: The highest mean total, legal and sublegal densities (10.00, 7.00 and 3.00 urchins/m^2, respectively) all occurred at a single quadrat surveyed in the deepest depth range (11.0 to 12.2 m, or 36 to 40 ft, Table 6d, Fig. 3d). The next highest total density (5.38 ± 1.56 urchins/m^2) occurred at a depth range of 0.3 to 1.5 m (1 to 5 ft) below CD (n=13, Table 6d, Fig. 3d). From this depth range, there was a gradual decrease in densities down to the 4.9 to 6.1 m (16 to 20 ft) depth range, and then a gradual increase in density down to the deepest depth, as discussed previously. This is very different from the usual pattern of a gradual decrease in total densities with each increment of depth throughout the whole surveyed depth range, as observed in most other surveys and sites.

Substrate: The most frequently observed substrate in the Plumper Islands was smooth bedrock (48 quadrats, with a total mean density of 2.33 ± 0.32 urchins/m^2; Table 7d; Fig. 4d). The highest mean total (3.93 ± 0.92 urchins/m^2) and legal (2.71 urchins/m^2) densities occurred on creviced bedrock, whereas the highest mean sublegal density (1.40 urchins/m^2) was observed on cobble.

(iv) Dissection Data

Lab measurements were performed using the same method initiated in October 2002 (Waddell and Perry 2005). There were 135 green sea urchins that were randomly collected from all depths and all locations and fully measured and analyzed in the same method as in all previous surveys (Table 8). In addition, there were an extra 119 urchins collected (in total) from all of the sites and measured for test height, test diameter and total wet weight. Therefore, there are two sample sizes presented in Table 8. These additional measurements were taken in order to calculate a more accurate test diameter/wet weight relationship (i.e. providing a larger sample size, without spending an inordinate amount of time with all of the other measurements and dissections, and without killing the animals).

The legal-sized green urchins randomly selected from Stubbs Island had the largest mean measurements for the entire lab measurements collected in October 2008 (Table 8). In contrast, the legal-sized urchins randomly selected from the Plumper Islands generally had the smallest mean lab measurements for all lab measurements acquired, except for the mean drained weight, the mean stomach and contents weight, and the mean gonad weight, all of which were second largest. Sublegal-mature-sized urchins randomly selected from the Plumper Islands also had the smallest mean measurements

for all lab measurements taken, whereas measurements from urchins of the same size range collected from the Stephenson Islets were generally the largest of the three survey sites (except for the mean drained weight, the mean stomach and contents weight, and the mean gonad weight, which were all second largest (Table 8)).

These results are different from the field survey data (which had a much larger sample size than the lab data). The field survey data show that the mean legal-sized test diameters and mean weights were largest at the Plumper Islands (not the smallest, as in the lab results), and the smallest mean legal TD's and mean weights occurred at the Stephenson Islets (Table 4). In addition, the field survey data showed that the largest mean test diameters and mean weights for sublegal-mature urchins occurred at Stubbs Island, and these same parameters were smallest at the Plumper Islands.

A test for homogeneity of regression slopes showed there was no significant difference between the slopes of the regression lines for the relationship between test diameter and the natural log transformation (to approximate normality) of the total wet weight for the three separate sites (F value = 2.22 with df = 251 and $p < 0.05$). However, there was a significant difference between the slopes of the regression lines for the relationship between test diameter and the total wet weight (no natural log transformation) for the three separate sites (F value = 7.38 with df = 251 and $p < 0.05$). It was therefore decided that individual allometric equations $(W=\alpha TD^{\beta})$ be used for each site in the October 2008 survey when calculating the total wet weight (in grams) from the TD (in millimeters).

The best (i.e., highest R^2) power relationships were calculated between TD (in millimeters) and test heights (in millimeters; Figs. 5 and 6), TD (in millimeters) and total wet weight (in grams; Figs. 7 and 8), and TD (in millimeters) and gonad weight (in grams; Figs. 9 and 10), for all sites combined and for each of the three sites separately, using EXCEL (see figures for equations).

Roe quality is determined by both colour and texture, the best quality having an orange/yellow colour and a firm texture. During the October 2008 survey, legal-sized urchins with the highest percentage of the best quality roe (53.9% with both colour and texture codes =1, Table 9) were observed at the Plumper Islands, closely followed by urchins from Stubbs Island (53.3%), in contrast to the lowest percentage at the Stephenson Islets (42.9%). However, the highest percentage of sublegal-sized green urchins with the highest percentage of best quality roe were from the Stephenson Islets (42.9%). The mean roe recovery rate (total gonad weight (all grades) divided by the total drained weight of all urchins sampled) for legal-sized green urchins ranged from a high of 16.9% at Stubbs Island to a low of 14.7% at the Stephenson Islets (Table 9).

(v) Biomass Estimates

The mean total density at the Stephenson Islets in October 2008 (11.75 urchins/m^2; Table 5) was extrapolated over the total area between zero and 10 m below CD (485,200 m^2), to derive that there were 5,701,100 ± 908,102 green sea urchins of all sizes at this site (Table 10). This included 2,079,680 ± 278,598 legal-sized, 3,257,520 ±

831,512 sublegal-mature, and 363,900 ± 76,455 immature green urchins. The TD-total wet weight relationship for the Stephenson Islets (from the dissection data for all urchins from the Stephenson Islets in October 2008 (Fig. 8a)) was applied to all the test measurements recorded in the field for the Stephenson Islets. Mean individual wet weights were then calculated for the three size classes. The mean weights per legal-sized, sublegal-mature-sized and immature-sized green sea urchin from Stephenson Islets were determined to be 74.0 ± 0.8 g, 30.4 ± 0.4 g, and 3.2 ± 0.1 g, respectively (Table 4). Multiplying the individual weights with the abundances gave total biomasses of 153.97 ± 20.64 t, 98.98 ± 25.28 t, and 1.17 ± 0.25 t for legal-sized, sublegal-mature and sublegal-immature green sea urchins at Stephenson Islets in October 2008 (Table 10). The overall total biomass was 254.12 ± 32.64 t.

By extrapolating the mean densities (Table 5) over the total area at Stubbs Island, it was determined that there were 149,200 ± 66,327 green urchins in total, of which 94,800 ± 37,743 were of legal size, 46,800 ± 26,087 that were sublegal-mature, and 7,600 ± 2,719 that were immature (Table 10). The mean individual wet weights, calculated using the TD-total wet weight relationship for Stubbs Island urchins only (Fig. 8b), were 87.0 ± 1.3 g, 37.1 ± 1.2 g, and 3.2 ± 0.3 g for legal-sized, sublegal-mature-sized, and sublegal-immature green urchins, respectively (Table 4). The total biomass at Stubbs Island in October 2008 was 10.01 ± 3.43 t (Table 10). This was comprised of 8.25 ± 3.28 t of legal-sized urchins, 1.74 ± 0.97 t of sublegal-mature urchins, and 0.02 ± 0.01 t of sublegal-immature urchins.

The estimated numbers of green urchins in the Plumper Islands survey site in October 2008, based on the calculated mean densities (Table 5), were 241,409 ± 117,128 legal-sized urchins, 213,706 ± 40,098 sublegal-mature urchins, and 61,342 ± 23,501 immature green urchins, for a total of 516,457 ± 152,269 green urchins (Table 9). The mean individual wet weights were calculated using the TD-total wet weight relationship for Plumper Island urchins only (Fig. 8c). They were 88.9 ± 2.1 g (much larger than in the previous survey), 20.1 ± 1.2 g, and 3.7 ± 0.3 g for legal-sized, sublegal-mature, and sublegal-immature urchins, respectively (Table 4). Based on these values, the biomass estimates were 21.46 ± 10.42 t of legal-sized urchins, 4.29 ± 0.82 t of sublegal-mature urchins, and 0.23 ± 0.09 t of immature urchins, for a total biomass estimate of 25.98 ± 10.46 t (Table 10).

(b) NOVEMBER 8 and 10, 2010 SURVEY

The weather was calm with overcast skies and sunny breaks on the first day of this survey (November 8, 2010). However, it became very stormy on November 9, and surveying had to be cancelled for the day, but resumed again on November 10. Due to strong currents and shortage of daylight hours, there were two less transects surveyed at the Stephenson Islets (Table 1; Fig. 1b; 8 transects instead of 10, missed Transect 7 and 10), one less transect surveyed at Stubbs Island (Fig. 1c; 3 transects instead of 4, missed Transect 16), but all four transects were surveyed at the Plumper Islands (Fig. 1c, Table 1).

Size: There were 475 quadrats surveyed in total, of which 377 were fully measured. Of the total 3,532 green urchins observed during this survey, 1,585 (44.9%) were legal-sized, 1,745 (49.4%) were sublegal-mature, and 202 (5.7%) were sublegal-immature (after adjustments for unmeasured urchins; Table 11). The size frequency distribution for the whole survey is presented in Fig. 11a, and the size frequency analysis is presented in Table 12. There were two dominant size modes (26 and 55 mm TD) for all of the sites combined ($X^2 = 159.7$; df = 36; $p < 0.0001$). The mean TD's and weights for all sites combined were 62.3 ± 0.2 mm and 73.9 ± 0.6 g for legal-sized urchins, 43.9 ± 0.2 mm and 29.3 ± 0.4 g for sublegal-mature urchins, and 18.7 ± 0.4 mm and 2.8 ± 0.1 g for sublegal-immature urchins (Table 13).

Density: In November 2010, the mean total density for all sites combined was 7.44 ± 1.42 urchins/m^2 (Table 14). The mean overall densities (after adjustment for unmeasured urchins) for legal-sized, sublegal-mature-sized, and immature green urchins were 3.34 ± 0.65, 3.67 ± 0.83, and 0.43 ± 0.10 urchins/m^2, respectively (Table 14).

Depth: The highest mean total (13.38 ± 1.81), legal-sized (6.48 urchins/m^2), and sublegal-sized (6.90 urchins/m^2) density for all sites combined occurred in the 0.3 to 1.5 m (or 1 to 5 ft) below CD depth range (Table 15a; Fig. 12a).

Substrate: The mean total densities of all substrate types (all sites combined) ranged from a low of 2.43 ± 0.93 urchins/m^2 for gravel (n=21; Table 16a and Fig. 13a), to 22.33 ± 11.35 urchins/m^2 for crushed shell (n=3). The most frequently sampled substrate (247 quadrats of 473) was smooth bedrock, with a mean total density of 8.66 ± 0.68 urchins/m^2 (Table 16a, Fig. 13a). There were no observations of green urchins on sand, mud, or whole shell in any of the quadrats sampled in this survey.

(i) Stephenson Islets

Size: In November 2010 there were 196 quadrats that were fully surveyed (measured), and 98 that were counted only, for a total of 294 surveyed quadrats. After adjusting for unmeasured urchins, there were 1,239 (42.9%) legal-sized, 1,500 (52.0%) sublegal-mature-sized, and 146 (5.1%) sublegal-immature (or a total of 2,885) green urchins observed in 8 transects at the Stephenson Islets (Table 11). The size frequency analysis (Table 12 and Fig. 11b) showed there were two dominant modes, at 30 and 54 mm TD ($X^2 = 117.1$; df = 31; $p < 0.0001$). Mean TD's and weights for urchins from Stephenson Islets were 60.5 ± 0.2 mm and 72.1 ± 0.6 g for legal-sized green urchins, 45.0 ± 0.3 mm and 33.1 ± 0.4 g for sublegal-mature urchins, and 17.7 ± 0.6 mm and 2.7 ± 0.2 g for sublegal-immature urchins (Table 13).

Density: The mean total, legal, sublegal-mature and sublegal-immature densities at the Stephenson Islets (after adjusting for the unmeasured urchins) were 9.81 ± 1.62, 4.21 ± 0.82, 5.10 ± 0.98, and 0.50 ± 0.14 urchins/m^2, respectively (Table 14). The highest mean total (16.49 urchins/m^2), legal-sized (7.45 urchins/m^2), and sublegal-immature (1.06 urchins/m^2) densities were observed at Transect 11, while the highest mean sublegal-mature density (8.28 urchins/m^2), was observed at Transect 9 (Table 14).

Depth: The highest mean total (19.08 ± 2.58 urchins/m^2), legal (9.31 urchins/m^2) and sublegal (9.77 urchins/m^2) densities all occurred in the 0.3 to 1.5 m (1 to 5 ft) below CD depth range (n=26 quadrats; Table 15b; Fig. 12b). The mean densities below this depth generally decreased gradually with each depth increment.

Substrate: The mean total densities of all main substrate types at the Stephenson Islets ranged from a low of 3.93 ± 1.55 urchins/m^2 for boulders (n=14; Table 16b and Fig. 13b), to 22.33 ± 11.35 urchins/m^2 for crushed shell (n=3). The most frequently sampled substrate (137 of 292 quadrats) was smooth bedrock, with a mean total density of 12.01 ± 1.01 urchins/m^2 (Table 16b, Fig. 13b).

(ii) Stubbs Island

Size: There were 54 quadrats that were fully surveyed at Stubbs Island, and 391 green urchins of all sizes that were measured (Table 11). This included 225 (57.5%) legal-sized, 139 (35.5%) sublegal-mature, and 27 (6.9%) sublegal-immature urchins. The analysis of the size frequency distribution (Table 12 and Fig. 11c) revealed there were two main frequency modes lying at 25 and 60 mm TD (X^2 = 45.9; df = 27; p 0.0131). Mean TD's and weights of urchins at Stubbs Island in November 2010 were: 65. ± 0.4 mm and 77.0 ± 1.5 g for legal-sized urchins; 42.2 ± 0.8 mm and 23.6 ± 1.1 g for sublegal-mature urchins; and 20.8 ± 0.4 mm and 2.6 ± 0.1 g for sublegal-immature urchins (Table 13).

Density: The mean overall total density for the three transects surveyed at Stubbs Island was 7.24 ± 2.32 urchins/m^2 (Table 14), and the mean overall legal, sublegal-mature and sublegal-immature densities were 4.17 ± 0.87 urchins/m^2, 2.57 ± 1.29 urchins/m^2, and 0.50 ± 0.24 urchins/m^2, respectively. The highest mean densities at Stubbs Island by transect occurred at Transect 17, where the mean total, legal, sublegal-mature and sublegal-immature densities were 10.00, 5.03, 4.17 and 0.79 urchins/m^2, respectively (Table 14). Similar to past surveys, the lowest mean densities for all size categories occurred at Transect 18.

Depth: At Stubbs Island in November 2010, the highest mean total density (15.91 ± 3.57 urchins/m^2) occurred in the 0.3 to 1.5 m (1 to 5 ft) below CD and the densities in general gradually decreased with depth (Table 15c, Fig. 12c). Both the highest mean legal-sized (8.45 urchins/m^2) and sublegal-sized (7.45 urchins/m^2) densities occurred in this depth range.

Substrate: Smooth bedrock was observed at 50 of 54 total quadrats, and had the highest mean density (7.62 ± 1.38 urchins/m^2; Table 16c). Creviced bedrock was observed in the other 4 quadrats, and had a much lower and more variable density (2.50 ± 2.18 urchins/m^2).

(iii) Plumper Islands

Size: During the November 2010 survey, there were 4 transects and a total of 127 fully surveyed quadrats in the Plumper Islands (Table 1). There were 256 green urchins measured, of which 121 (47.3%) were of legal size, 106 (41.4%) were sublegal-mature,

and 29 (11.3%) were sublegal-immature (Table 11). The size frequency distribution is presented in Fig. 11d and Table 12 presents the results of the test diameter frequency analysis. There were two main frequency modes, occurring at 31 and 67 mm TD (X^2 = 70.0; df = 30; p <0.0001). The mean TD's and weights were 68.4 ± 0.6 mm and 95.2 ± 2.3 g for legal-sized urchins, 37.0 ± 0.9 mm and 19.1 ± 1.3 g for sublegal-mature-sized urchins and 20.1 ± 0.4 mm and 3.0 ± 0.2 g for immature-sized urchins (Table 13).

Density: The mean total overall density of the four transects surveyed at the Plumper Islands was 2.02 ± 0.64 urchins/m^2 (Table 14). The mean legal, sublegal-mature and sublegal-immature densities were 0.95, 0.83 and 0.23 urchins/m^2, respectively (Table 14).

Depth: In contrast to the other sites where the highest densities occurred in very shallow waters, the highest density of green urchins in the Plumper Islands were observed at the deepest depth range surveyed, from 9.4 to 10.7 m (31 to 35 ft) below CD (Table 15d, Fig. 12d). A similar trend occurred at the Plumper Islands in October 2008. The total, legal and sublegal densities at this depth range were 6.40 ± 2.75, 3.60, and 2.80 urchins/m^2, respectively (Table 15d, Fig. 12d).

Substrate: The most commonly observed substrate in the Plumper Islands was smooth bedrock (60 of 127 quadrats), while there were no observations of pea gravel, sand, mud, whole shell or crushed shell (Table 16d). The highest mean total density (3.46 ± 0.95 urchins/m^2) occurred on boulders (n=26; Table 16d, Fig. 13d).

(iv) Dissection Data

Complete lab measurements were taken from 128 green sea urchins randomly collected from all locations (see sample size 2 in Table 17). An additional 149 green urchins were randomly collected from all locations for test height, test diameter and total wet weight measurements only (see sample size 1 in Table 17). These additional measurements were taken in order to calculate a more accurate test diameter/wet weight relationship (i.e., by providing a larger sample size) without spending an inordinate amount of time with the other measurements.

The dissection results (Table 17) indicated that the legal-sized urchins randomly selected from Stubbs Island (n=35) had the largest mean test heights, test diameters (equal to the Plumper Islands), and total wet weights, while these same measurements were second largest for urchins from the Plumper Islands (n=40) and smallest for urchins from the Stephenson Islets (n=68). The field survey data results were different from these data, and instead indicated that the mean legal test diameters and total wet weights were largest for green urchins measured at the Plumper Islands (n=125; Table 13), followed by Stubbs Island (n=224), and smallest at the Stephenson Islets (N=776). Lab measurements showed that the mean drained weights, mean gutted weights, and the mean stomach and content weights were largest for urchins collected from Stubbs Island (n=14; Table 17), and the mean gonad weights were highest for urchins from the Plumper Islands (n=12).

A test for homogeneity of regression slopes showed there was a significant difference between the slopes of the regression lines for the relationship between test diameter and the natural log transformation (to approximate normality) of the total wet weight for the three separate sites (F value = 5.37 with df = 2, 274 and $p < 0.05$). Therefore individual allometric equations $(W=\alpha TD^{\beta})$ were used for each site in the November 2010 survey when calculating the total wet weight (in grams) from the TD (in millimeters).

The best (i.e., highest R^2) power relationships were calculated between TD (in millimeters) and test heights (in millimeters; Figs. 14 and 15), TD (in millimeters) and total wet weight (in grams; Figs. 16 and 17), and TD (in millimeters) and gonad weight (in grams; Figs. 18 and 19), for all sites combined and for each of the three sites separately, using EXCEL (see figures for equations).

Roe quality is determined by both colour and texture, the best quality having a bright orange/yellow colour and a firm texture. During the November 2010 survey, legal-sized urchins with the highest percentage of the best quality roe (75.0% with both colour and texture = 1, Table 18) were again observed at the Plumper Islands, with the lowest at only 22.6% at the Stephenson Islets. However, the sublegal-sized green urchins with the highest percentage of best quality roe were from Stubbs Island (41.7%). The mean roe recovery rate (total gonad weight (all grades) divided by the total drained weight of all urchins sampled) for legal-sized green urchins ranged from a high of 14.5% at Stubbs Island to a low of 9.8% at the Plumper Islands (Table 18).

(v) Biomass Estimates

The mean total density at the Stephenson Islets in November 2010 (9.81 urchins/m^2; Table 14) was extrapolated over the total area between zero and 10 m below CD (485,200 m^2), to determine there was a total of 4,761,231 ± 786,487 green sea urchins of all sizes at this site (Table 19). The total is comprised of 2,044,771 ± 395,507 legal-sized, 2,475,510 ± 475,780 sublegal-mature-sized, and 240,950 ± 68,321 immature green urchins. The test for homogeneity showed there was a significant difference between the slopes of the TD-total wet weight regressions for the three sites. Therefore the TD-total wet weight relationship derived from the dissection data for urchins collected from the Stephenson Islets only (Fig. 17a) was applied to each individual test measurement recorded in the field for the Stephenson Islets, and mean individual wet weights were calculated for the three size classes. The mean weights per legal-sized, sublegal-mature-sized and immature-sized green sea urchin from Stephenson Islets were determined to be 72.1 ± 0.6 g, 33.1 ± 0.4 g, and 2.7 ± 0.2 g, respectively (Table 13). The individual weights were multiplied with the abundances to give total biomasses of 147.53 ± 28.55 t, 82.03 ± 15.78 t, and 0.66 ± 0.19 t for legal-sized, sublegal-mature and sublegal-immature green sea urchins at Stephenson Islets in November 2010 (Table 19). The overall total biomass was 230.22 ± 32.62 t.

A total of 141,919 ± 45,457 green urchins was estimated at Stubbs Island by extrapolating the mean densities (Table 14) over the total area. This included 81,667 ± 17,091 legal-sized urchins, 50,452 ± 25,313 sublegal-mature-sized urchins, and 9,800 ±

4,694 sublegal-immature urchins (Table 19). The TD-total wet weight relationship for Stubbs Island urchins was used to calculate the mean individual wet weights (Fig. 17b), which were 77.0 ± 1.5 g for legal-sized, 23.6 ± 1.1 g for sublegal-mature-sized, and 2.6 ± 0.1 g for sublegal-immature green urchins (Table 13). The biomasses for legal-sized, sublegal-mature-sized, immature-sized, and all urchin size classes combined at Stubbs Island in November 2010 were 6.29 ± 1.32 t, 1.19 ± 0.60 t, 0.03 ± 0.01 t, and 7.50 ± 1.45 t, respectively (Table 19).

The estimated numbers of green urchins in the Plumper Islands survey site in November 2010, based on the calculated mean densities (Table 14), were 213,036 ± 104,003 legal-sized urchins, 186,627 ± 45,209 sublegal-mature urchins, and 51,058 ± 16,496 sublegal-immature urchins, for a total of 450,721 ± 143,292 green urchins (Table 19). The mean individual wet weights were calculated using the TD-total wet weight relationship for Plumper Island urchins only (Fig. 17c). They were 95.2 ± 2.3 g, 19.1 ± 1.3 g, and 3.0 ± 0.2 g for legal-sized, sublegal-mature, and sublegal-immature urchins, respectively (Table 13). The biomass estimates were 20.28 ± 9.91 t of legal-sized urchins, 3.57 ± 0.88 t of sublegal-mature urchins, and 0.15 ± 0.05 t of immature urchins, for a total biomass estimate of 24.01 ± 9.95 t (Table 19).

(c) THE FISHERY

The British Columbia green sea urchin fishery started in 1987, and has had many management restrictions placed on it as it has developed over the years (e.g. Perry *et al.* 2002). Restrictions in the number of licenses and of harvesting techniques (hand-picking by divers only), a minimum size limit of 55 mm, Management Area closures, area quotas, Individual Quotas (IQ's), and fishing seasons are all controls that managers have put in place to regulate this fishery. The Pacific Fishery Management Areas (PFMAs) 12, 13A, 13B, 13C, 18, and 19 were open to green sea urchin commercial fishing during all of the commercial fishing seasons from 2007/08 to 2011/12. The quota allowed for Area 12 (where the study area is located) was 252,974 lbs (114.75 t) for each of these fishing seasons.

Similar to what has been observed since 2001/02 fishing season, there continues to be an oversupply of green sea urchins on the Japanese market, primarily supplied from Russia, which has caused the global price of green urchins to drop dramatically. The Japanese buyers have not been as interested in buying green urchins from B.C. because they have been able to get an ample supply from Russia for a lower price. The B.C. processors have only been able to sell to Japan when the weather was too rough for the Russian packers to travel (D & D Pacific Fisheries Ltd. 2002). In addition, the cost of transporting the product to Japan has increased dramatically (D & D Fisheries Ltd. 2009). As a result, only part of the Total Allowable Catch (TAC) for green sea urchins has been harvested for the last many years (Table 20). The low point was in the 2006/07 fishing season, when only 10.9% of the TAC was achieved. There has been a gradual improvement over the past several fishing seasons, with 32.1%, 36.0% and 50.0% of the TAC harvested in 2007/08, 2008/09 (DFO 2010), and 2009/10, respectively.

(d) FISHING EXPLOITATION

The exploitation of green sea urchins from the Stephenson Islets during each fishing season was calculated using equations 5 and 6 in the Methods Section. Basically, the fishing exploitation represents the amount of legal-sized green sea urchins harvested from the Stephenson Islets by the fishing industry over the fishing season, divided by the legal-sized biomass just prior to the opening of the fishery. The exploitation at Stephenson Islets was 0.033 ± 0.004 during the 2008/09 fishing season and 0.011 ± 0.002 during the 2010/11 fishing season (Table 21).

DISCUSSION

Initially conducted every fall and spring, this series of surveys in Queen Charlotte Strait are currently only conducted every second fall, due to budget constraints. Therefore, survey results will be compared to the previous survey, conducted in October 2006 (Waddell and Perry 2007).

(a) SIZE DISTRIBUTION CHANGES

The size frequency distributions have been different for each of the three sites in each of the various surveys. Despite our intensive sampling (n=1,677 in October 2008 at Stephenson Islets, and n=1,805 in November 2010), these changes in size frequency distribution are difficult to analyze and interpret. Green sea urchins have the potential for discontinuous growth, which fluctuates with the availability and species of vegetation (Himmelman *et al.* 1983, Larson *et al.* 1980, Vadas 1977, Vadas *et al.* 2002). Munk (1992) noted that growth rates of green urchins in Alaska varied seasonally (higher in spring and summer and lower in fall and winter), and decreased with increasing age. Therefore, test size is considered an unreliable index of age, making it difficult to identify distinct age classes. Munk (1992) did produce von Bertalanffy estimates of mean size at age for green sea urchins in Alaska, and estimated that ages 1.0 through 4.0 were 9.9, 29.3, 44.0 and 55.1 mm. He also noted that the modes became obscure after age 3 as growth slowed and they merged with a multi-age group above 50 mm. We expect there are many age classes with wide variations and overlaps in test diameter so that individual modes blend together and camouflage separate age classes. However, if we use Munk's (1992) size-at-age estimates, then we assume that green urchins in this survey area are in the sublegal-immature size class at age 1.0, in the sublegal-mature size class at age 2.0 and age 3.0, and could reach the legal size limit (>= 55 mm) by about age 4.0. We use these only as general guidelines in interpreting the general pattern of each size distribution and how they have changed since the previous survey.

As in past surveys, we used the computer program "MIX3aa" (Macdonald 1994) to analyze the size distribution data of urchins measured in the October 2008 and November 2010 surveys. In October 2006, the size frequency distribution for each of the three survey sites had a unimodal shape, with the single mode mean ranging from 48 mm at the Stephenson Islets to 53 mm at Stubbs Island (Waddell and Perry 2007). Over the next two years, the size distribution shifted to a bimodal arrangement for all three sites in October 2008. During this survey there appeared to be a larger mode (population

proportion of 0.55 at Plumper Islands to 0.90 at Stubbs Island) with a mean ranging from 53 mm at the Stephenson Islets to 62 mm at the Plumper Islands. The second smaller mode (population proportion of 0.10 at Stubbs Island to 0.45 at Plumper Islands) had a mean ranging from 23 mm at Stubbs Island to 29 mm at the Plumper Islands. In November 2010, the size frequency distribution remained generally unchanged from October 2008. There was still a bimodal frequency distribution, with a larger mode (population proportion varied from 0.51 at Plumper Islands to 0.82 at both Stephenson Islets and Stubbs Island) that had a mean ranging from 54 mm at the Stephenson Islets to 67 mm at the Plumper Islands, and a second smaller mode (population proportion of 0.18 at Stephenson Islets and Stubbs Island to 0.49 at Plumper Islands) with a mean ranging from 25 mm at Stubbs Island to 31 mm at the Plumper Islands. This seems to show that between October 2006 and October 2008, the population structure shifted from a dominance of sublegal-mature-sized urchins, to one with a dual dominance of sublegal – immature and legal-sized urchins at all three locations.

Similarly, when examining the changes in percentages, legal-sized urchins increased at all three sites from October 2006 to October 2008 (especially at Stubbs Island, from 47.5% to 63.5%), and then increased again at the Stephenson Islets and the Plumper Islands from October 2008 to November 2010, but decreased at Stubbs Island. The percentage of sublegal-mature green urchins decreased from October 2006 to October 2008 at all three sites, and from October 2008 to November 2010 it decreased at the Stephenson Islets, increased at Stubbs Islands, and remained unchanged at the Plumper Islands. The percentage of immature green urchins at the Stephenson Islets was at its lowest level of all fall surveys in October 2006 at 2.1% (Waddell and Perry 2007), but increased to 6.4% in October 2008 and decreased again slightly to 5.1%, considered average levels amongst past surveys.

These results suggest that after poor juvenile recruitment in October 2006 (Waddell and Perry 2007), there was a successful spawn/recruitment between the spring of 2007 and October 2008. Additionally, the size frequency distribution for the Stephenson Islets appears to have shifted to the right by October 2008, showing a decrease in sublegal-mature urchins and an increase in legal-sized urchins. Following the October 2006 survey, there were no green urchins commercially harvested from the Stephenson Islets during the 2006/07 fishing season, and only 0.9 t harvested during the 2007/08 season. As a result, fewer of the legal-sized urchins would have been removed from the population, and more of the sublegal-sized urchins from October 2006 would have grown into the legal-size range by October 2008. The immature urchins in November 2010 indicate there was further recruitment of juveniles between the spring of 2009 and November 2010. The size frequency distribution shows a slight decrease of legal-sized urchins at the Stephenson Islets in November 2010, which also makes sense, as there was 5.06 t and 10.46 t of legal-sized green urchins harvested from the Stephenson Islets in the 2008/09 and 2009/10 fishing seasons, respectively (i.e., more harvested than in recent years).

When comparing among sites, the percentage of legal-sized urchins was highest at Stubbs Island, followed by the Plumper Islands, and lowest at the Stephenson Islets, in

both October 2008 and November 2010. This was expected, as legal-sized urchins are usually harvested at the Stephenson Islets annually but are not supposed to be harvested at the other two locations.

(b) LENGTH-WEIGHT RELATIONSHIPS

When comparing between sites, the largest mean legal-sized TD's and highest mean total wet weights for green urchins measured in the field, during both the October 2008 and November 2010 surveys, were observed at the Plumper Islands, followed by Stubbs Island, and were smallest for the Stephenson Islets. This is exactly as one would expect, as there is commercial removal of legal-sized urchins at Stephenson Islets, resulting in a lowering of the mean overall mean size of legal urchins (assuming there is low immigration).

When comparing amongst all surveys at Stephenson Islets, both the mean legal TD and the mean sublegal-immature TD were the largest observed in October 2008, while the mean legal total wet weights were average for these size classes in that survey. In November 2010, mean legal and immature TD's and total wet weights were average. However, during this survey, the mean sublegal-mature TD was the largest for all of the surveys, while the mean total wet weight remained an average size at this location.

It should also be noted that at Stubbs Island, the mean legal total wet weight was lowest for all surveys at this location in the November 2010 survey. In addition, the highest observed mean legal TD at Plumper Islands among all surveys at this location was observed in November 2010.

(c) DENSITY

(i) General Changes

The mean densities at the Stephenson Islets increased for all size classes between October 2006 and October 2008. Further, the mean legal and mean sublegal-mature densities in October 2008 were the highest observed of all surveys since 1995 at the Stephenson Islets, while the sublegal-immature densities were the second highest. This is consistent with only 0.939 t of green urchins harvested from the Stephenson Islets between October 2006 and October 2008, so very few legal-sized urchins were removed, while more sublegal-sized urchins were growing into the legal-size. In contrast, there was 15.5 t of legal-sized green urchins harvested there between October 2008 and November 2010, and consequently, the mean legal density at Stephenson Islets decreased from October 2008 to November 2010. Nonetheless, the mean legal density in November 2010 was the second highest of all the surveys since 1995.

The mean legal density at Stubbs Island increased from October 2006 to October 2008, and then decreased in November 2010, (similar to the Stephenson Islets), whereas the mean legal densities at the Plumper Islands decreased between all of these surveys. The mean densities of all size classes at Stubbs Island and the Plumper Islands were

average for both October 2008 and November 2010 as compared to all surveys since 1996.

When comparing among the three sites, the highest mean density of legal-sized urchins in October 2008 occurred at Stubbs Island (as observed every survey since November 1999). This is as expected as the urchins have not been commercially harvested here. However, in November 2010, the highest mean density of legal-sized urchins occurred at the Stephenson Islets, slightly higher than the density at Stubbs Island.

(ii) Changes with Depth

Although there were subtle differences in depth distributions between the sites and size classes, in general, green sea urchins in this study area have occurred at greater densities in shallower waters during past surveys, and have decreased in density with increasing depth. Himmelman (1986) also observed that green urchin abundances generally decreased at greater depths, and studies in Maine by Grabowski *et al.* (2005) found that biomass was almost exclusively found in the 0 – 5 m depth zone. This was the general pattern for green urchins at the Stephenson Islets and Stubbs Island in October 2008, and November 2010. While only one urchin was observed shallower than 1.2 m above CD, (Stephenson Islets in October 2008), the highest mean densities of green urchins for all size categories at the Stephenson Islets and Stubbs Island occurred between 1.2 m above CD to 1.5 m below CD. However, the distribution was different at the Plumper Islands. Although the second highest densities occurred between 1.0 to 5.0 m below CD for all size categories at the Plumper Islands in October 2008, the highest densities for all size categories occurred between 11.0 to 12.2 m (but n=1 quadrat). In November 2010, the highest densities for all size categories at the Plumper Islands were observed between 9.4 to 10.7 m below CD (n=10 quadrats; note that this was the deepest depth surveyed in November 2010). Although these deeper depth distributions are not always seen at the Plumper Islands, they are similar to distributions seen in previous surveys at this location. It is unknown why urchins in the Plumper Islands occur in higher densities at deeper depth intervals in some years, but possibly green sea urchins at this site depend more upon drift algae than attached algae and must go deeper to find it.

(iii) Changes with Substrate

The type of substrate where the highest densities of urchins occur seems to vary with survey, site, and size class. During the October 2008 survey, the highest total mean density by main substrate occurred on boulders at the Stephenson Islets (but with a large SE), on cobble at Stubbs Island (n=2, so large SE again), and on creviced bedrock at the Plumper Islands. During the November 2010 survey, the highest total mean density by main substrate occurred on crushed shell (n=3, with very large SE), followed by smooth bedrock at the Stephenson Islets, on smooth bedrock at Stubbs Island, and on boulders at the Plumper Islands. This supports results of past surveys in this survey area, where green urchins were observed more consistently and in higher densities on smooth and creviced bedrock, boulders, cobble and shell, less frequently on gravel or pea gravel, and almost never on sand.

(d) DISSECTION RESULTS

In October 2008, the mean stomach weight for legal-sized urchins in Stephenson Islets was the lowest observed of all the surveys conducted there since 1995, while the mean stomach weight of legal-sized urchins was the second highest for all surveys at Stubbs Island, and third highest for all surveys at the Plumper Islands. Mean stomach weights for sublegal-mature urchins in October 2008 were average when compared to past surveys, except for the Plumper Islands, where they were the lowest observed. The mean stomach weights in November 2010 were average for legal and sublegal-mature urchins at all three sites when compared to past surveys, except for sublegal-mature urchins in Stephenson Islets, which were the lowest ever observed at that location. The mean gonad weights for legal and sublegal-mature urchins from all three sites in October 2008 and November 2010 were among the lowest observed of all of the past surveys.

(e) CHANGES IN BIOMASS

Because the majority of green urchins are found in shallow waters in the autumn, we estimated the "total area" of green sea urchin habitat for the biomass calculations as "all area with a depth range of 0 to 10 m below CD". Contour line data for this depth range were also available, simplifying the estimation of this field. However, it is recognized that green sea urchins have a wide range in habitable depth, so these are conservative estimates. The area estimates are largest (485,200 m^2) for the Stephenson Islets, so it is not surprising that the biomass estimates are highest for that location. The area estimate for the Plumper Islands (223,600 m^2) is about half the size as for the Stephenson Islets, and the biomass estimates are always smaller. Stubbs Island has the smallest area estimate (19,600 m^2, only 4% of the area of the Stephenson Islets), and always has a much smaller biomass estimate than the other two sites.

During the first three years of surveys both pre- and post-fishery surveys were conducted, meaning that changes in the total legal-sized biomass could be calculated between the start and finish of a fishing season at the Stephenson Islets (Waddell *et al.* 1997, 2002, 2003). Post-season surveys were subsequently eliminated due to funding restraints. However, changes in biomass between years can still be calculated. The estimate of total biomass of legal-sized green urchins at the Stephenson Islets site almost doubled from 87.00 ± 22.58 t in October 2006 (Waddell and Perry 2007) to 153.97 ± 20.64 t in October 2008 (Table 10), and represented the highest biomass observed for all surveys since 1995. There were no green sea urchins commercially harvested from the Stephenson Islets during the 2006/07 fishing season, and very little harvested during 2007/08 season (0.94 t, Table 21). The legal-sized biomass at Stephenson remained high with a slight decrease between October 2008 and November 2010 (147.53 ± 28.55 t; Table 19), after 5.06 t and 10.46 t were harvested from the Stephenson Islets during the 2008/09 and 2009/10 fishing seasons, respectively (Table 21). The legal biomass therefore actually increased twice, by (153.97 + 0.94 - 87.00 =) 67.91 t (equivalent to a 77% increase) from October 2006 to October 2008 and increased by (147.53 + 5.06 + 10.46 – 153.97 =) 9.08 t (equivalent to a 5.9% increase) from October 2008 to November 2010. Although there was a decrease from October 2008 to November 2010, the legal biomass at Stephenson Islets remained the second highest compared to all other past surveys.

At Stephenson Islets, the biomass estimate of sublegal-mature green urchins increased from 85.71 ± 14.47 t in October 2006 (Waddell and Perry 2007) to 98.98 ± 25.28 t in October 2008, an increase of 13.27 t or 15.5% over two years (i.e., essentially the same as the previous two year period). Like the legal biomass, this represented the highest sublegal-mature biomass for the Stephenson Islets over all of the surveys since 1995. Subsequently, the sublegal-mature biomass decreased to 82.03 ± 15.78 t from October 2008 to November 2010, a decrease of 16.95 t, or 17.1%, but remained the second highest sublegal-mature biomass for this location over all other past surveys. The biomass estimate of immature urchins at Stephenson Islets increased from 0.30 ± 0.09 t in October 2006 (Waddell and Perry 2007) to 1.17 ± 0.25 t in October 2008, the second largest biomass estimate over all of the surveys since 1995. The biomass then decreased to 0.66 ± 0.19 t in November 2010. The biomass of immature green urchins varies tremendously from season to season.

The overall total (all sizes combined) biomass estimate for the Stephenson Islets increased from 173.01 ± 26.82 t in October 2006 (Waddell and Perry 2007) to 254.12 ± 32.64 t in October 2008, and then decreased slightly to 230.22 ± 32.62 in November 2010. We have not taken into account the biomass of legal-sized urchins removed by the fishery each year, and this will be discussed further in another paper.

The biomass estimate of legal-sized urchins at Stubbs Island increased from 6.12 ± 4.52 t in October 2006 (Waddell and Perry 2007), to 8.25 ± 3.28 t in October 2008, but decreased again in November 2010 to 6.29 ± 1.32 t (close to its level in 2006). The biomass estimates of sublegal-mature urchins at Stubbs Island decreased from 2.30 ± 1.78 t in October 2006 (Waddell and Perry 2007), to 1.74 ± 0.97 t in October 2008, (close to its previous level in November 2004 (1.76 ± 0.81 t; Waddell and Perry 2006)), and then decreased again to 1.19 ± 0.60 t. The biomass estimate of immature urchins increased from 0.005 ± 0.003 t in October 2006 (Waddell and Perry 2007) to 0.02 ± 0.01 t in October 2008 and increased again in November 2010 to 0.03 ± 0.01 t.

After having a huge increase (20.64 t or 444%) in the biomass of legal-sized urchins at the Plumper Islands from 4.65 t in November 2004 (Waddell and Perry 2006) to 25.29 ± 5.69 t in October 2006 (Waddell and Perry 2007), the legal biomass remained similar in October 2008 and November 2010 (21.46 ± 10.42 t and 20.28 ± 9.91 t, respectively. This supports our previous suggestion that the value in November 2004 was not a good estimate as only one transect was completed in that survey (Waddell and Perry 2006, 2007).

(f) FISHING EXPLOITATION

Exploitation is calculated as the proportion of the biomass of legal-sized green urchins harvested by the fishery from the Stephenson Islets to the estimated total biomass of legal-sized urchins at the Stephenson Islets just prior to the opening of the fishery. Analyzing why the exploitation varies between years is difficult because there are many variables influencing this calculation. The total biomass estimates are influenced by the

density estimates, which may vary depending on the transects surveyed (not always the same), and by the estimated mean individual weights of the legal-sized green urchins, which also seem to vary between surveys. The amount commercially harvested from the Stephenson Islets during any particular fishing season is influenced not only by the density of legal-sized green urchins available for harvesting, but also by the dynamics of the fishery, such as the supply and demand of the market, the price per pound, directions to the fishers by the processors, fishery management regulations and changes, other fisheries competing for fishers' time, weather, and various other industry-related factors. The Japanese market for green urchin roe has been in flux since approximately 2001-02, meaning that the amount of green urchins commercially harvested is less influenced by the amount of legal-sized urchins available for harvesting and more influenced by the dynamics of the market. The demand for the product is low due to competition from other countries, therefore the price per pound is low and the fishers choose not to harvest (or the buyers lower their request for product).

Fishing exploitation was last calculated for the Stephenson Islets for the 2004/05 fishing season at 0.12 ± 0.02 (Waddell and Perry 2006). There was no commercial fishing of green sea urchins at the Stephenson Islets in either of the 2005/06 or 2006/07 fishing seasons, so exploitation was 0. Also, exploitation could not be calculated for the 2007/08 or 2009/10 fishing seasons because green urchin research surveys were not conducted in either the fall of 2007 or 2009. Exploitation was calculated for 2008/09 at 0.033 ± 0.004, about a fourth of the exploitation in 2004/05. However, this has more to do with a lowering of the market demand for British Columbia green urchins than it has to do with urchin stocks, densities, or availability.

SUMMARY

The hallmark features for the previous green sea urchin survey in October 2006 were unimodal size frequency distributions at all three sites, low total wet weights for all size classes at all sites, the lowest mean gonad weights for legal-sized urchins at Stephenson Islets and Stubbs Island ever observed, and some of the lowest mean densities of immature green urchins (at all three sites) observed over the history of surveys conducted here (indicating there had been poor spawning/juvenile recruitment success).

From October 2006 to October 2008, the size frequency distributions at all three sites transformed from unimodal (with the size frequency mode mean in the sublegal-mature size range) to bimodal (with the mode means closer to the immature and legal-size ranges). The mean stomach weight for legal-sized urchins was the lowest observed at Stephenson Islets, while it was the second highest observed at Stubbs Island, and the third highest observed at the Plumper Islands. The mean stomach weight for sublegal-mature urchins was the lowest observed the Plumper Islands. At Stephenson Islets, the mean legal and immature TD's were the largest observed, while the corresponding mean total wet weights were average to low. The mean legal and sublegal-mature biomass estimates and densities at Stephenson Islets in October 2008 were the highest observed of all surveys since 1995 at this site, while the mean sublegal-immature biomass estimate

and density were the second highest observed. The mean densities of immature green urchins increased from October 2006 to October 2008 at all the sites, by four times at Stephenson Islets, up to 13.5 times at Plumper Islands. However, the mean densities of all size classes at Stubbs Island and the Plumper Islands were average in October 2008 as compared to all past surveys, including the immature densities. This suggests that although the mean immature urchin densities improved, there does not appear to have been a highly significant juvenile recruitment event during this time period, as seen in other years.

The size frequency distributions in November 2010 remained bimodal for all three sites, although all of the frequency modes shifted slightly to the right, indicating increases in the mean sizes. The mean sublegal-mature stomach weights at Stephenson Islets were the lowest observed at this location. The mean legal and immature TD's and total wet weights were of average size at Stephenson Islets, while the mean sublegal-mature TD was the largest observed over all of the past surveys. The mean legal total wet weight was the lowest observed at the Plumper Islands. Some of the lowest mean legal and sublegal-mature gonad weights were observed in November 2010 at all three sites (and the absolute lowest of 12 surveys at Stubbs Island, for both size classes). The mean legal and sublegal-mature biomass estimates and densities decreased at all three sites from October 2008 to November 2010 (except for the mean sublegal-mature density at Stubbs Island). Despite this, the mean legal density and biomass estimate at the Stephenson Islets in November 2010 were still second highest only to these corresponding measurements observed in October 2008.

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Table 1. Survey dates, vessels involved, and number of transects surveyed at each of the sites, for the October 2008 and November 2010 green urchin surveys. (WCGUA = owned by a commercial fisher of the WCGUA, DFO = owned by the DFO). .

Survey Dates	Vessels Involved	Number of Transects Surveyed		
		Stephenson Islets	Stubbs Island	Plumper Islands
October 18-19, 2008	*"Emma III"* (WCGUA) *"C68"* (DFO)	8	3	4
November 8 and 10, 2010	*"CCC"* (WCGUA) *"C68"* (DFO)	8	3	4

Table 2. Numbers (N) and percentages (P) of green sea urchins of legal size, sublegal-mature size, sublegal-immature size, unknown size (i.e., counted only), and all sizes (total) for all sites, measured during the October 2008 survey. Note that measuring was incomplete (urchins were measured in most quadrats but only counted in the remainder) for both of these surveys. The numbers in the brackets in the lighter font indicate the actual measured values while the darker font indicates the best estimates (the "unknowns" were proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and a zero value was assigned to the unknowns). (M=measured quadrats; T=measured plus counted quadrats; Legal ≥ 55 mm test diameter (TD); Sublegal-mature = 25 mm ≤ TD < 55 mm TD; Sublegal-immature = < 25 mm; Total Number = total number of green sea urchins measured).

Site	Survey Date	No. of Quads	N or P	Number of Legal	Number of Sublegal-mature	Number of Sublegal-immature	Number of Unknown	Total Number
All Sites Combined	Oct. 2008	437 T 311 M	N P	**1,540** (895) **39.8%** (23.1%)	**2,076** (1,047) **53.6%** (27.0%)	**257** (142) **6.6%** (3.7%)	**0** (1,788) **0%** (46.2%)	**3,873**
Stephenson Islets	Oct. 2008	275 T 149 M	N P	**1,181** (536) **36.5%** (16.6%)	**1,851** (822) **57.2%** (25.4%)	**207** (92) **6.4%** (2.8%)	**0** (1,788) **0%** (55.2%)	**3,238**
Stubbs Island	Oct. 2008	49 T 49 M	N P	**237** **63.5%**	**117** **31.4%**	**19** **5.1%**	**0** **0%**	**373**
Plumper Islands	Oct. 2008	113 T 113 M	N P	**122** **46.7%**	**108** **41.4%**	**31** **11.9%**	**0** **0%**	**261**

Table 3. Green sea urchin test diameter frequency distribution analysis for the October 2008 survey. Results were obtained using the analysis software "Mix 3aa" (Macdonald 1994). (Sigma = standard deviation, X^2 = chi-square goodness of fit value, DF = degrees of freedom, P-value = the p-value of the chi-square test).

Site	Survey	Frequency Mode	Mode Mean (mm)	Sigma (mm)	Proportion Of Population	X^2	DF	P-value
All Sites Combined	Oct. 2008	1 2	26 55	6.7 9.7	0.16 0.84	82.1	34	<0.0001
Stephenson Islets	Oct. 2008	1 2	25 53	6.1 9.8	0.13 0.87	58.8	31	0.0019
Stubbs Island	Oct. 2008	1 2	23 58	6.7 8.6	0.10 0.90	30.9	31	0.4724
Plumper Islands	Oct. 2008	1 2	29 62	8.0 7.6	0.45 0.55	45.7	34	0.0863

Table 4. Means and standard errors (SE) of test diameters (TD) (using October 2008 field survey data) and weight (using TD-total wet weight relationships from October 2008 lab measurements, and applying to field survey data) of legal, sublegal-mature and immature green sea urchins from each of the survey sites. (Legal ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD).

Site	Size	Sample Size	Mean TD (mm)	SE of Mean TD (mm)	Mean Weight (g)	SE of Mean Weight (g)
All Sites Combined	Legal	1132	62.6	0.2	76.9	0.6
	Sublegal-Mature	1170	43.7	0.2	29.9	0.4
	Sublegal-Immature	153	19.8	0.3	3.2	0.1
Stephenson Islets	Legal	680	62.1	0.2	74.0	0.8
	Sublegal-Mature	905	44.3	0.3	30.4	0.4
	Sublegal-Immature	92	19.9	0.4	3.2	0.1
Stubbs Island	Legal	311	62.9	0.3	87.0	1.3
	Sublegal-Mature	147	45.6	0.7	37.1	1.2
	Sublegal-Immature	26	19.0	0.8	3.2	0.3
Plumper Islands	Legal	141	64.3	0.5	88.9	2.1
	Sublegal-Mature	118	36.2	0.8	20.1	1.2
	Sublegal-Immature	35	20.1	0.7	3.7	0.3

Table 5. Sample mean densities (urchins/m^2) by transect and overall standard errors for green sea urchins of legal size, sublegal-mature size, immature size, unknown size, and all sizes (total) in the October 2008 survey. (Legal = ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD, Unknown = unmeasured, Total Density = density of all urchins combined. The numbers in the brackets indicate calculations where the unknowns have been proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and assigning a zero value to the unknowns. M=measured quadrats; T=total quadrats (measured and counted). Stephenson Islets = Transects 3 to 14, Stubbs Island = Transects 15 to 18, and Plumper Islands = Transects 20 to 23).

Transect Number	Number of Quadrats	Legal Density	Sublegal – Mature Density	Sublegal – Immature Density	Unknown Density	Total Density
3	32 M 50 T	2.22 (**4.42**)	1.74 (**3.46**)	0.22 (**0.44**)	4.14 (**0.00**)	**8.32**
5A	10 M 20 T	1.70 (**4.35**)	0.95 (**2.40**)	0.10 (**0.25**)	4.25 (**0.00**)	**7.00**
6	7 M 15T	1.80 (**4.13**)	0.33 (**0.73**)	0.13 (**0.33**)	2.93 (**0.00**)	**5.20**
8	10 M 17 T	2.47 (**4.35**)	1.41 (**2.47**)	0.24 (**0.41**)	3.12 (**0.00**)	**7.24**
9	25 M 50 T	1.24 (**2.76**)	6.08 (**13.54**)	0.60 (**1.34**)	9.72 (**0.00**)	**17.64**
10	10 M 18 T	2.06 (**3. 61**)	1.18 (**2.11**)	0.06 (**0.11**)	2.44 (**0.00**)	**5.83**
13	27 M 55 T	2.67 (**6.47**)	3.96 (**9.60**)	0.35 (**0.84**)	9.93 (**0.00**)	**16.91**
14	28 M 51 T	1.53 (**3.53**)	2.84 (**6.59**)	0.45 (**1.04**)	6.33 (**0.00**)	**11.16**
Stephenson Islets Totals or Avg.	149 M 276 T	1.95 ± 0.23 (**4.29 ± 0.57**)	2.99 ± 0.73 (**6.71 ± 1.71**)	0.33 ± 0.07 (**0.75 ± 0.16**)	6.48 ± 1.16 (**0.00**)	**11.75 ± 1.87**
15	16 T	**8.63**	**5.06**	**0.63**	0.00	**14.31**
17	20 T	**4.05**	**1.65**	**0.40**	0.00	**6.10**
18	13 T	**1.38**	**0.23**	**0.08**	0.00	**1.69**
Stubbs Island Totals or Avg.	49 M 49 T	**4.84 ± 1.93**	**2.39 ± 1.33**	**0.39 ± 0.14**	**0.00**	**7.61 ± 3.38**
20	34 T	**1.35**	**0.91**	**0.26**	0.00	**2.53**
21	31 T	**0.26**	**0.55**	**0.10**	0.00	**0.90**
22	28 T	**2.43**	**1.04**	**0.57**	0.00	**4.04**
23	20 T	**0.00**	**1.55**	**0.15**	0.00	**1.70**
Plumper Islands Totals or Avg.	113 M 113 T	1.08 ± 0.52	0.96 ± 0.18	0.27 ± 0.11	0.00	2.31 ± 0.68
OVERALL TOTAL	311 M 438 T	2.05 ± 0.35 (**3.52 ± 0.58**)	2.40 ± 0.56 (**4.74 ± 1.38**)	0.32 ± 0.05 (**0.59 ± 0.13**)	4.08 ± 1.22 (**0.00**)	**8.85 ± 1.80**

Table 6a. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD from all survey sites combined in the October 2008 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	1	1.00	0.00	1.00
-4 to 0	-1.2 to 0.0	47	10.26	6.28	16.53 ± 2.13
1 to 5	0.3 to 1.5	62	9.60	9.15	18.74 ± 2.28
6 to 10	1.8 to 3.0	70	5.59	6.83	12.41 ± 1.62
11 to 15	3.3 to 4.8	56	4.00	4.54	8.54 ± 1.31
16 to 20	4.9 to 6.1	59	1.64	6.20	7.85 ± 1.27
21 to 25	6.4 to 7.6	100	1.64	2.42	4.06 ± 0.52
26 to 30	7.9 to 9.1	56	1.16	2.11	3.27 ± 0.55
31 to 35	9.4 to 10.7	29	0.76	2.41	3.17 ± 0.70
36 to 40	11.0 to 12.2	1	7.00	3.00	10.00

Table 6b. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD in the Stephenson Islets in the October 2008 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	1	1.00	0.00	1.00
-4 to 0	-1.2 to 0.0	32	11.41	7.78	19.19 ± 2.63
1 to 5	0.3 to 1.5	42	10.43	13.29	23.71 ± 2.98
6 to 10	1.8 to 3.0	40	7.55	10.48	18.03 ± 2.27
11 to 15	3.3 to 4.8	31	4.77	7.16	11.94 ± 1.84
16 to 20	4.9 to 6.1	36	1.44	10.19	11.64 ± 1.80
21 to 25	6.4 to 7.6	74	1.50	3.12	4.62 ± 0.63
26 to 30	7.9 to 9.1	38	1.39	2.53	3.92 ± 0.75
31 to 35	9.4 to 10.7	10	1.20	3.90	5.10 ± 1.78
36 to 40	11.0 to 12.2	0			

Table 6c. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD at Stubbs Island in the October 2008 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number Of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	0			
-4 to 0	-1.2 to 0.0	6	14.67	6.83	21.50 ± 5.35
1 to 5	0.3 to 1.5	7	9.00	4.71	13.71 ± 2.88
6 to 10	1.8 to 3.0	7	8.14	6.43	14.57 ± 4.39
11 to 15	3.3 to 4.8	11	4.91	2.45	7.36 ± 3.28
16 to 20	4.9 to 6.1	8	2.25	1.13	3.38 ± 1.19
21 to 25	6.4 to 7.6	6	4.50	1.83	6.33 ± 2.46
26 to 30	7.9 to 9.1	5	0.40	0.20	0.60 ± 0.40
31 to 35	9.4 to 10.7	5	0.40	1.20	1.60 ± 0.51
36 to 40	11.0 to 12.2	0			

Table 6d. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD in the Plumper Islands in the October 2008 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	0			
-4 to 0	-1.2 to 0.0	9	2.33	1.44	3.78 ± 2.01
1 to 5	0.3 to 1.5	13	3.62	1.77	5.38 ± 1.56
6 to 10	1.8 to 3.0	23	0.96	1.04	2.00 ± 0.31
11 to 15	3.3 to 4.8	14	0.57	1.36	1.93 ± 0.32
16 to 20	4.9 to 6.1	15	0.47	0.67	1.13 ± 0.35
21 to 25	6.4 to 7.6	20	0.55	0.75	1.30 ± 0.52
26 to 30	7.9 to 9.1	13	0.77	1.62	2.38 ± 0.68
31 to 35	9.4 to 10.7	14	0.57	1.79	2.36 ± 0.50
36 to 40	11.0 to 12.2	1	7.00	3.00	10.00

Table 7a. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from all survey sites combined in the October 2008 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	221	2.28	2.82	4.59	9.69 ± 0.83
2	Bedrock (crevices)	98	2.46	3.96	6.20	12.62 ± 1.39
3	Boulder	36	1.92	1.83	2.11	5.86 ± 1.78
4	Cobble	54	1.37	1.78	1.65	4.80 ± 0.94
5	Gravel	16	0.25	0.81	0.00	1.06 ± 0.28
6	Pea Gravel	11	0.09	0.36	0.00	0.45 ± 0.16
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	1	1.00	0.00	0.00	1.00

Table 7b. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from the Stephenson Islets in the October 2008 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	128	1.84	3.36	7.93	13.13 ± 1.25
2	Bedrock (crevices)	84	2.42	4.42	7.24	14.07 ± 1.56
3	Boulder	10	3.50	3.20	7.60	14.30 ± 5.30
4	Cobble	42	1.43	1.86	2.12	5.40 ± 1.13
5	Gravel	0				
6	Pea Gravel	11	0.09	0.36	0.00	0.45 ± 0.16
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	0				

Table 7c. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from Stubbs Island in the October 2008 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	45	4.91	2.84	0.00	7.76 ± 1.36
2	Bedrock (crevices)	0				
3	Boulder	2	1.50	2.00	0.00	3.50 ± 3.50
4	Cobble	2	6.50	2.00	0.00	8.50 ± 7.50
5	Gravel	0				
6	Pea Gravel	0				
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	0				

Table 7d. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from the Plumper Islands in the October 2008 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	48	0.98	1.35	0.00	2.33 ± 0.32
2	Bedrock (crevices)	14	2.71	1.21	0.00	3.93 ± 0.92
3	Boulder	24	1.29	1.25	0.00	2.54 ± 0.92
4	Cobble	10	0.10	1.40	0.00	1.50 ± 0.52
5	Gravel	16	0.25	0.81	0.00	1.06 ± 0.28
6	Pea Gravel	0				
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	1	1.00	0.00	0.00	1.00

Table 8. Summary results of measurements taken during green urchin dissections in the October 2008 survey. (Legal ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD. SE = Standard Error; Gutted Weight = stomach and contents removed; Gonad Colour: 0=unknown or no sample, 1=orange/yellow, 2=yellow with other colours, 3=brown/red; Gonad Texture: 0=unknown or no sample, 1=firm, 2=semi-firm, 3=flimsy; Sex: 1=male, 2=female, 3=juvenile or unknown. Sample Size 1 is for test height, TD and total wet weight. Sample Size 2 is for all other calculations).

Summary Information			LOCATION								
			STEPHENSON ISLETS			STUBBS ISLAND			PLUMPER ISLANDS		
			Legal	Sublegal-mature	Sublegal-immature	Legal	Sublegal-mature	Sublegal-immature	Legal	Sublegal-mature	Sublegal-immature
Sample Size 1			61	50	11	32	23	2	32	38	5
Mean Test Height (mm) ± SE			35.1 (± 0.5)	24.0 (± 0.6)	10.2 (± 0.6)	36.0 (± 0.9)	23.2 (± 1.1)	11.0 (± 2.0)	32.6 (± 0.6)	19.7 (± 0.8)	11.0 (± 0.3)
Mean Test Diameter (mm) ± SE			66.3 (± 0.9)	45.6 (± 1.0)	19.9 (± 0.9)	69.0 (± 1.8)	43.3 (± 1.9)	21.0 (± 3.0)	64.7 (± 1.2)	38.3 (± 1.3)	22.4 (± 0.7)
Mean Total Wet Weight (g) ± SE			92.5 (± 3.8)	34.1 (± 2.0)	3.3 (± 0.4)	116.5 (± 9.1)	32.7 (± 3.5)	4.0 (± 1.6)	89.6 (± 4.9)	23.5 (± 2.4)	4.4 (± 0.3)
Sample Size 2			29	35	8	15	11	1	13	19	4
Mean Drained Weight (g) ± SE			58.7 (± 2.9)	25.2 (± 1.8)	2.5 (± 0.3)	82.2 (± 7.2)	26.3 (± 3.8)	5.1	66.1 (± 4.8)	14.2 (± 1.6)	4.0 (± 0.4)
Mean Gutted Weight (g) ± SE			45.9 (± 2.3)	19.1 (± 1.4)	1.8 (± 0.2)	58.7 (± 5.8)	18.3 (± 2.7)	3.1	45.5 (± 3.4)	9.5 (± 1.1)	2.8 (± 0.2)
Mean Stomach and Contents Weight (g) ± SE			12.8 (± 0.9)	6.1 (± 0.5)	0.7 (± 0.1)	23.4 (± 1.9)	8.0 (± 1.2)	2.0	20.7 (± 1.9)	4.7 (± 0.6)	1.2 (± 0.2)
Sex	% Male		7	17	0	27	36	0	62	11	0
	% Female		17	11	0	67	27	0	31	37	0
	% Unknown		76	71	100	7	36	100	8	53	100
Gonad	Mean Weight (g) ± SE		8.3 (± 0.8)	2.8 (± 0.4)	0.0	13.9 (± 1.9)	2.9 (± 0.6)	0.0	10.4 (± 1.1)	1.5 (± 0.4)	0.2 (± 0.1)
	Colour Proportion	0	0.03	0.06	0.75	0.00	0.00	1.00	0.00	0.00	0.25
		1	0.52	0.63	0.25	0.60	1.00	0.00	0.54	1.00	0.75
		2	0.17	0.23	0.00	0.20	0.00	0.00	0.31	0.00	0.00
		3	0.28	0.09	0.00	0.20	0.00	0.00	0.15	0.00	0.00
		4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Texture Proportion	0	0.03	0.06	0.75	0.00	0.00	1.00	0.00	0.00	0.25
		1	0.52	0.43	0.13	0.87	0.27	0.00	0.92	0.37	0.00
		2	0.41	0.49	0.13	0.13	0.73	0.00	0.00	0.63	0.75
		3	0.03	0.03	0.00	0.00	0.00	0.00	0.08	0.00	0.00

Table 9. Comparisons of percentage of highest roe quality (roe with best colour and texture) and mean roe recovery rates (total gonad weight divided by total drained weight) at Stephenson Islets, Stubbs Island and Plumper Islands in October 2008. (Sample size = total number of urchins with roe).

Location	Sample Size		Highest Quality Roe		Mean Roe Recovery Rates	
	Legal	Sublegal	Legal	Sublegal	Legal	Sublegal
Stephenson Islets October 2008	28	35	42.9%	42.9%	14.7%	11.5%
Stubbs Island October 2008	15	11	53.3%	27.3%	16.9%	11.1%
Plumper Islands October 2008	13	22	53.9%	31.8%	15.8%	10.2%

Table 10. Calculated total abundance (number) and biomass (tonnes) of green sea urchins by site and size category in October 2008, with standard errors (incorporates estimates from unknowns). (Legal ≥ 55 mm test diameter (TD), Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD. Biomass estimates were calculated using TD-weight relationships determined from October 2008 lab measurements for each of the three sites separately, and applied to the field survey TD measurements).

Size Category	Stephenson Islets	Stubbs Island	Plumper Islands
Number of Legal-sized	2,079,680 ± 278,598	94,800 ± 37,743	241,409 ± 117,128
Number of Sublegal-mature	3,257,520 ± 831,512	46,800 ± 26,087	213,706 ± 40,098
Number of Sublegal-immature	363,900 ± 76,455	7,600 ± 2,719	61,342 ± 23,501
Number of all sizes	5,701,100 ± 908,102	149,200 ± 66,327	516,457 ± 152,269
Biomass of Legal-size (t)	153.97 ± 20.64	8.25 ± 3.28	21.46 ± 10.42
Biomass of Sublegal-mature (t)	98.98 ± 25.28	1.74 ± 0.97	4.29 ± 0.82
Biomass of Sublegal-immature (t)	1.17 ± 0.25	0.02 ± 0.01	0.23 ± 0.09
Total Biomass (t)	254.12 ± 32.64	10.01 ± 3.43	25.98 ± 10.46

Table 11. Numbers (N) and percentages (P) of green sea urchins of legal size, sublegal-mature size, sublegal-immature size, unknown size (i.e., counted only), and all sizes (total) for all sites, measured during the November 2010 survey. Note that measuring was incomplete (urchins were measured in most quadrats but only counted in the remainder) for both of these surveys. The numbers in the brackets in the lighter font indicate the actual measured values while the darker font indicates the best estimates (the "unknowns" were proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and a zero value was assigned to the unknowns). (M=measured quadrats; T=measured plus counted quadrats; Legal ≥ 55 mm test diameter (TD); Sublegal-mature = 25 mm ≤ TD < 55 mm TD; Sublegal-immature = < 25 mm; Total Number = total number of green sea urchins measured).

Site	Survey Date	No. of Quads	N or P	Number of Legal	Number of Sublegal-mature	Number of Sublegal-immature	Number of Unknown	Total Number
All Sites Combined	Nov. 2010	475 T 377 M	N P	**1,585** (1,118) **44.9%** (31.7%)	**1,745** (1,178) **49.4%** (33.4%)	**202** (147) **5.7%** (4.2%)	**0** (1,089) **0%** (30.8%)	**3,532**
Stephenson Islets	Nov. 2010	294 T 196 M	N P	**1,239** (774) **42.9%** (26.8%)	**1,500** (934) **52.0%** (32.4%)	**146** (91) **5.1%** (3.2%)	**0** (1,086) **0%** (37.6%)	**2,885**
Stubbs Island	Nov. 2010	54 T 54 M	N P	**225** (224) **57.5%** (57.3%)	**139** **35.5%**	**27** **6.9%**	**0** (1) **0%** (0.3%)	**391**
Plumper Islands	Nov. 2010	127 T 127 M	N P	**121** (120) **47.3%** (46.9%)	**106** (105) **41.4%** (41.0%)	**29** **11.3%**	**0** (2) **0%** (0.8%)	**256**

Table 12. Green sea urchin test diameter frequency distribution analysis for the November 2010 survey. Results were obtained using the analysis software "Mix 3aa" (Macdonald 1994). (Sigma = standard deviation, X^2 = chi-square goodness of fit value, DF = degrees of freedom, P-value = the p-value of the chi-square test).

Site	Survey	Frequency Mode	Mode Mean (mm)	Sigma (mm)	Proportion Of Population	X^2	DF	P-value
All Sites Combined	Nov. 2010	1 2	26 55	7.7 9.5	0.16 0.84	159.7	36	<0.0001
Stephenson Islets	Nov. 2010	1 2	30 54	11.0 7.8	0.18 0.82	117.1	31	<0.0001
Stubbs Island	Nov. 2010	1 2	25 60	4.9 10.0	0.18 0.82	45.9	27	0.0131
Plumper Islands	Nov. 2010	1 2	31 67	10.1 8.0	0.49 0.51	70.0	30	<0.0001

Table 13. Means and standard errors (SE) of test diameters (TD) (using November 2010 field survey data) and weight (using TD-total wet weight relationships from November 2010 lab measurements, and applying to field survey data) of legal, sublegal-mature and immature green sea urchins from each of the survey sites. (Legal ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD).

Site	Size	Sample Size	Mean TD (mm)	SE of Mean TD (mm)	Mean Weight (g)	SE of Mean Weight (g)
All Sites Combined	Legal	1125	62.3	0.2	73.9	0.6
	Sublegal-Mature	1185	43.9	0.2	29.3	0.4
	Sublegal-Immature	148	18.7	0.4	2.8	0.1
Stephenson Islets	Legal	776	60.5	0.2	72.1	0.6
	Sublegal-Mature	937	45.0	0.3	33.1	0.4
	Sublegal-Immature	92	17.7	0.6	2.7	0.2
Stubbs Island	Legal	224	65.2	0.4	77.0	1.5
	Sublegal-Mature	139	42.2	0.8	23.6	1.1
	Sublegal-Immature	27	20.8	0.4	2.6	0.1
Plumper Islands	Legal	125	68.4	0.6	95.2	2.3
	Sublegal-Mature	109	37.0	0.9	19.1	1.3
	Sublegal-Immature	29	20.1	0.4	3.0	0.2

Table 14. Sample mean densities (urchins/m^2) by transect and overall standard errors for green sea urchins of legal size, sublegal-mature size, immature size, unknown size, and all sizes (total) in the November 2010 survey. (Legal = ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD, Unknown = unmeasured, Total Density = density of all urchins combined. The numbers in the brackets indicate calculations where the unknowns have been proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and assigning a zero value to the unknowns. M=measured quadrats; T=total quadrats (measured and counted). Stephenson Islets = Transects 3 to 14, Stubbs Island = Transects 15 to 18, and Plumper Islands = Transects 20 to 23).

Transect Number	Number of Quadrats	Legal Density	Sublegal – Mature Density	Sublegal – Immature Density	Unknown Density	Total Density
3	27 M 55 T	2.02 (**3.85**)	2.84 (**5.40**)	0.05 (**0.11**)	4.45 (**0.00**)	**9.36**
5A	36 M 36 T	3.47 (**3.56**)	1.92 (**1.97**)	0.56 (**0.56**)	0.14 (**0.00**)	**6.08**
6	13 M 25T	3.68 (**6.28**)	1.28 (**2.20**)	0.28 (**0.48**)	3.72 (**0.00**)	**8.96**
8	8 M 15 T	2.53 (**5.07**)	0.87 (**1.73**)	0.00 (**0.00**)	3.40 (**0.00**)	**6.80**
9	37 M 40 T	3.80 (**4.40**)	7.18 (**8.28**)	0.28 (**0.33**)	1.75 (**0.00**)	**13.00**
11	32 M 47 T	3.87 (**7.45**)	4.15 (**7.98**)	0.55 (**1.06**)	7.91(**0.00**)	**16.49**
13	18 M 31 T	1.71 (**3.23**)	3.90 (**7.35**)	0.16 (**0.29**)	5.10 (**0.00**)	**10.87**
14	25 M 45 T	0.47 (**0.89**)	1.36 (**2.60**)	0.42 (**0.80**)	2.04 (**0.00**)	**4.29**
Stephenson Islets Totals or Avg.	196 M 294 T	2.63 ± 0.50 (**4.21 ± 0.82**)	3.18 ± 0.73 (**5.10 ± 0.98**)	0.31 ± 0.08 (**0.50 ± 0.14**)	3.69 ± 0.97 (**0.00**)	**9.81 ± 1.62**
15	14 T	4.36 (**4.43**)	**1.14**	**0.29**	0.07 (**0.00**)	**5.86**
17	29 T	**5.03**	**4.17**	**0.79**	**0.00**	**10.00**
18	11 T	**1.55**	**0.18**	**0.00**	**0.00**	**1.73**
Stubbs Island Totals or Avg.	54 M 54 T	4.15 ± 0.88 (**4.17 ± 0.87**)	**2.57 ± 1.29**	**0.50 ± 0.24**	0.02 ± 0.02 (**0.00**)	**7.24 ± 2.32**
20	49 T	0.76 (**0.78**)	0.82 (**0.84**)	**0.31**	0.04 (**0.00**)	**1.92**
21	31 T	**0.23**	**0.26**	**0.06**	**0.00**	**0.55**
22	30 T	**2.40**	**1.03**	**0.37**	**0.00**	**3.80**
23	17 T	**0.24**	**1.53**	**0.06**	**0.00**	**1.82**
Plumper Islands Totals or Avg.	127 M 127 T	0.94 ± 0.47 (**0.95 ± 0.47**)	**0.83 ± 0.20**	**0.23 ± 0.07**	0.02 ± 0.01 (**0.00**)	**2.02 ± 0.64**
OVERALL TOTAL	377 M 475 T	2.35 ± 0.42 (**3.34 ± 0.65**)	2.48 ± 0.56 (**3.67 ± 0.83**)	0.31 ± 0.06 (**0.43 ± 0.10**)	2.29 ± 0.78 (**0.00**)	**7.44 ± 1.42**

Table 15a. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD from all survey sites combined in the November 2010 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	1	0.00	0.00	0.00
-4 to 0	-1.2 to 0.0	15	4.60	3.87	8.47 ± 2.70
1 to 5	0.3 to 1.5	52	6.48	6.90	13.38 ± 1.81
6 to 10	1.8 to 3.0	81	5.51	4.74	10.25 ± 1.28
11 to 15	3.3 to 4.8	78	4.46	4.60	9.06 ± 0.97
16 to 20	4.9 to 6.1	59	1.88	2.80	4.68 ± 0.90
21 to 25	6.4 to 7.6	85	1.86	2.96	4.82 ± 0.56
26 to 30	7.9 to 9.1	86	1.63	3.05	4.67 ± 0.74
31 to 35	9.4 to 10.7	29	1.72	2.34	4.07 ± 1.11
36 to 40	11.0 to 12.2	0			

Table 15b. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD in the Stephenson Islets in the November 2010 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	1	0.00	0.00	0.00
-4 to 0	-1.2 to 0.0	7	8.14	6.14	14.29 ± 4.93
1 to 5	0.3 to 1.5	26	9.31	9.77	19.08 ± 2.58
6 to 10	1.8 to 3.0	49	7.71	6.82	14.53 ± 1.78
11 to 15	3.3 to 4.8	56	5.89	5.57	11.46 ± 1.13
16 to 20	4.9 to 6.1	33	1.79	4.30	6.09 ± 1.24
21 to 25	6.4 to 7.6	54	1.83	4.33	6.17 ± 0.68
26 to 30	7.9 to 9.1	59	2.12	4.25	6.37 ± 1.00
31 to 35	9.4 to 10.7	15	0.73	2.60	3.33 ± 1.01
36 to 40	11.0 to 12.2	0			

Table 15c. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD at Stubbs Island in the November 2010 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number Of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	0			
-4 to 0	-1.2 to 0.0	2	4.00	0.50	4.50 ± 3.50
1 to 5	0.3 to 1.5	11	8.45	7.45	15.91 ± 3.57
6 to 10	1.8 to 3.0	9	4.67	3.33	8.00 ± 2.71
11 to 15	3.3 to 4.8	7	2.43	3.57	6.00 ± 3.14
16 to 20	4.9 to 6.1	9	4.78	1.33	6.11 ± 3.35
21 to 25	6.4 to 7.6	6	2.67	1.67	4.33 ± 3.43
26 to 30	7.9 to 9.1	7	0.71	0.43	1.14 ± 0.83
31 to 35	9.4 to 10.7	4	0.25	0.75	1.00 ± 0.71
36 to 40	11.0 to 11.3	0			

Table 15d. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below CD in the Plumper Islands in the November 2010 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft)	Depth Range (m)	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	0			
-4 to 0	-0.9 to 0.0	6	1.00	2.00	3.00 ± 1.15
1 to 5	0.3 to 1.5	15	0.20	1.47	1.67 ± 0.45
6 to 10	1.8 to 3.0	23	1.04	0.96	2.00 ± 0.61
11 to 15	3.3 to 4.8	15	0.33	1.20	1.53 ± 0.46
16 to 20	4.9 to 6.1	17	0.41	0.76	1.18 ± 0.41
21 to 25	6.4 to 7.6	25	1.48	0.56	2.04 ± 0.65
26 to 30	7.9 to 9.1	20	0.40	0.50	0.90 ± 0.38
31 to 35	9.4 to 10.7	10	3.60	2.80	6.40 ± 2.75
36 to 40	11.0 to 12.2	0			

Table 16a. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from all survey sites combined in the November 2010 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	247	2.96	3.03	2.67	8.66 ± 0.68
2	Bedrock (crevices)	125	1.71	3.34	2.24	7.30 ± 0.59
3	Boulder	40	2.05	1.25	0.33	3.63 ± 0.81
4	Cobble	35	1.43	1.83	2.74	6.00 ± 1.48
5	Gravel	21	0.57	1.38	0.48	2.43 ± 0.93
6	Pea Gravel	2	1.00	3.00	0.00	4.00 ± 4.00
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	3	9.00	3.33	10.00	22.33 ± 11.35

Table 16b. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from the Stephenson Islets in the November 2010 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	137	3.40	3.81	4.80	12.01 ± 1.01
2	Bedrock (crevices)	100	2.09	3.92	2.80	8.81± 0.64
3	Boulder	14	1.57	1.43	0.93	3.93± 1.55
4	Cobble	28	1.29	2.04	3.43	6.75± 1.69
5	Gravel	8	1.38	2.25	1.25	4.88± 1.87
6	Pea Gravel	2	1.00	3.00	0.00	4.00± 4.00
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	3	9.00	3.33	10.00	22.33 ± 11.35

Table 16c. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from Stubbs Island in the November 2010 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	50	4.44	3.16	0.02	7.62 ± 1.38
2	Bedrock (crevices)	4	0.50	2.00	0.00	2.50 ± 2.18
3	Boulder	0				
4	Cobble	0				
5	Gravel	0				
6	Pea Gravel	0				
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	0				

Table 16d. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by main substrate type from the Plumper Islands in the November 2010 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density = all urchins combined).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density and Standard Error
1	Bedrock (smooth)	60	0.70	1.13	0.03	1.87 ± 0.31
2	Bedrock (crevices)	21	0.14	0.86	0.00	1.00 ± 0.39
3	Boulder	26	2.31	1.15	0.00	3.46 ± 0.95
4	Cobble	7	2.00	1.00	0.00	3.00 ± 3.00
5	Gravel	13	0.08	0.85	0.00	0.92 ± 0.77
6	Pea Gravel	0				
7	Sand	0				
8	Shell	0				
9	Mud	0				
10	Crushed shell	0				

*Table 17. Summary results of measurements taken during green urchin dissections in the November 2010 survey. (Legal ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD. SE = Standard Error; Gutted Weight = stomach and contents removed; Gonad Colour: 0=unknown or no sample, 1=orange/yellow, 2=yellow with other colours, 3=brown/red; Gonad Texture: 0=unknown or no sample, 1=firm, 2=semi-firm, 3=flimsy; Sex: 1=male, 2=female, 3=juvenile or unknown. Sample Size 1 is for test height, TD and total wet weight. Sample Size 2 is for all other calculations. * n = 8; ** n = 15).*

Summary Information			LOCATION								
			STEPHENSON ISLETS			STUBBS ISLAND			PLUMPER ISLANDS		
			Legal	Sublegal-mature	Sublegal-immature	Legal	Sublegal-mature	Sublegal-immature	Legal	Sublegal-mature	Sublegal-immature
Sample Size 1			68	81	0	35	21	0	40	31	1
Mean Test Height (mm) ± SE			35.4 (± 0.4)	23.9 (± 0.6)	-	37.4 (± 1.0)	24.9 (± 0.9)	-	37.2 (± 0.8)	20.1 (± 0.9)	10.0
Mean Test Diameter (mm) ± SE			64.2 (± 0.7)	43.4 (± 0.9)	-	67.5 (± 1.4)	46.0 (± 1.4)	-	67.5 (± 1.1)	38.2 (± 1.5)	18.0
Mean Total Wet Weight (g) ± SE			83.0 (± 2.7)	30.1 (± 1.6)	-	98.6 (± 6.0)	31.4 (± 2.6)	-	98.4 (± 4.9)	21.5 (± 2.3)	2.5
Sample Size 2			31	39	0	14	12	0	12	20	0
Mean Drained Weight (g) ± SE			60.0 (± 2.9)	19.1 (± 1.7)	-	68.6 (± 5.6)	22.1 (± 2.6)	-	68.4* (± 5.8)*	17.2** (± 2.3)**	-
Mean Gutted Weight (g) ± SE			42.7 (± 2.1)	13.6 (± 1.3)	-	48.7 (± 4.0)	15.1 (± 1.9)	-	44.9 (± 4.4)	10.3 (± 1.5)	-
Mean Stomach and Contents Weight (g) ± SE			17.3 (± 1.0)	5.5 (± 0.5)	-	19.9 (± 2.0)	7.0 (± 0.8)	-	18.2* (± 1.5)*	5.8** (± 0.5)**	-
Sex	% Male		32	36	-	36	0	-	58	10	-
	% Female		55	18	-	57	75	-	42	55	-
	% Unknown		13	46	-	7	25	-	0	35	-
Gonad	Mean Weight (g) ± SE		7.8 (± 0.9)	2.2 (± 0.4)	-	10.0 (± 1.1)	2.1 (± 0.6)	-	11.0 (± 1.4)	1.5 (± 0.3)	-
	Colour Proportion	0	0.00	0.05	-	0.00	0.00	-	0.00	0.00	-
		1	0.23	0.72	-	0.36	0.83	-	0.83	0.95	-
		2	0.39	0.10	-	0.29	0.00	-	0.00	0.00	-
		3	0.26	0.05	-	0.21	0.08	-	0.00	0.00	-
		4	0.03	0.05	-	0.14	0.08	-	0.17	0.05	-
	Texture Proportion	0	0.00	0.05	-	0.00	0.00	-	0.00	0.00	-
		1	0.65	0.38	-	0.79	0.50	-	0.92	0.25	-
		2	0.32	0.51	-	0.21	0.42	-	0.08	0.70	-
		3	0.03	0.05	-	0.00	0.08	-	0.00	0.05	-

*Table 18. Comparisons of percentage of highest roe quality (roe with best colour and texture) and mean roe recovery rates (total gonad weight divided by total drained weight) at Stephenson Islets, Stubbs Island and Plumper Islands in November 2010. (Sample size = total number of urchins with roe; * n = 8; ** n = 15).*

Location	Sample Size		Highest Quality Roe		Mean Roe Recovery Rates	
	Legal	Sublegal	Legal	Sublegal	Legal	Sublegal
Stephenson Islets November 2010	31	37	22.6%	32.4%	13.1%	11.9%
Stubbs Island November 2010	14	12	35.7%	41.7%	14.5%	9.5%
Plumper Islands November 2010	12	20	75.0%	25.0%	9.8*%	17.9**%

Table 19. Calculated total abundance (number) and biomass (tonnes) of green sea urchins by site and size category in November 2010, with standard errors (incorporates estimates from unknowns). (Legal ≥ 55 mm test diameter (TD), Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD. Biomass estimates were calculated using TD-weight relationships determined from November 2010 lab measurements for each of the three sites separately, and applied to the field survey TD measurements).

Size Category	Stephenson Islets	Stubbs Island	Plumper Islands
Number of Legal-sized	2,044,771 ± 395,507	81,667 ± 17,091	213,036 ± 104,003
Number of Sublegal-mature	2,475,510 ± 475,780	50,452 ± 25,313	186,627 ± 45,209
Number of Sublegal-immature	240,950 ± 68,321	9,800 ± 4,694	51,058 ± 16,496
Number of all sizes	4,761,231 ± 786,487	141,919 ± 45,457	450,721 ± 143,292
Biomass of Legal-size (t)	147.53 ± 28.55	6.29 ± 1.32	20.28 ± 9.91
Biomass of Sublegal-mature (t)	82.03 ± 15.78	1.19 ± 0.60	3.57 ± 0.88
Biomass of Sublegal-immature (t)	0.66 ± 0.19	0.03 ± 0.01	0.15 ± 0.05
Total Biomass (t)	230.22 ± 32.62	7.50 ± 1.45	24.01 ± 9.95

Table 20. Percentage of the British Columbia green sea urchin Total Allowable Catch (TAC) achieved by fishing season. (Data courtesy of D & D Pacific Fisheries Ltd. 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, and 2010).

Fishing Season	% TAC harvested
2000/01	96.3
2001/02	68.7
2002/03	80.5
2003/04	90.3
2004/05	44.6
2005/06	22.6
2006/07	10.9
2007/08	32.1
2008/09	36.0
2009/10	50.0

Table 21. Fishing seasons for Area 12 (where the study area is located) and harvest details for the Stephenson Islets. The quota allowed for Area 12 was 252,974 lbs (114.747 t) for every fishing season from 2006/07 to 2010/11. (Data courtesy of DFO Shellfish Data Unit, PBS, Nanaimo, B.C.)

Fishing Season	Actual Fishing Period for Area 12	Total Landed in Area 12	% of Area 12 Quota Harvested	Harvest Weight from Stephenson Islets (lbs – t)	Stephenson Islets % of Area 12 Total Harvest	Exploitation at Stephenson Islets
2006/07	Dec.18, 2006 - Mar. 5, 2007	16,510 lbs (7.489 t)	6.5%	0	0	0
2007/08	Oct.29, 2007 – Mar. 21, 2008	56,477 lbs (25.617 t)	22.3%	2,070 lbs (0.939 t)	3.67	Unknown – no survey Fall 2007
2008/09	Oct.3, 2008- Mar. 31, 2009	78,931 lbs (35.802 t)	31.2%	11,159 lbs (5.062 t)	14.14	0.033 ± 0.004
2009/10	Oct. 5, 2009- Feb. 25, 2010	134,413 lbs (60.968 t)	53.1%	23,051 lbs (10.456 t)	17.15	Unknown – no survey Fall 2009
2010/11	Sep 16, 2010- Aug. 31, 2011	102,667 lbs (46.569 t)	40.6%	3,604 lbs (1.635 t)	3.51	0.011 ± 0.002

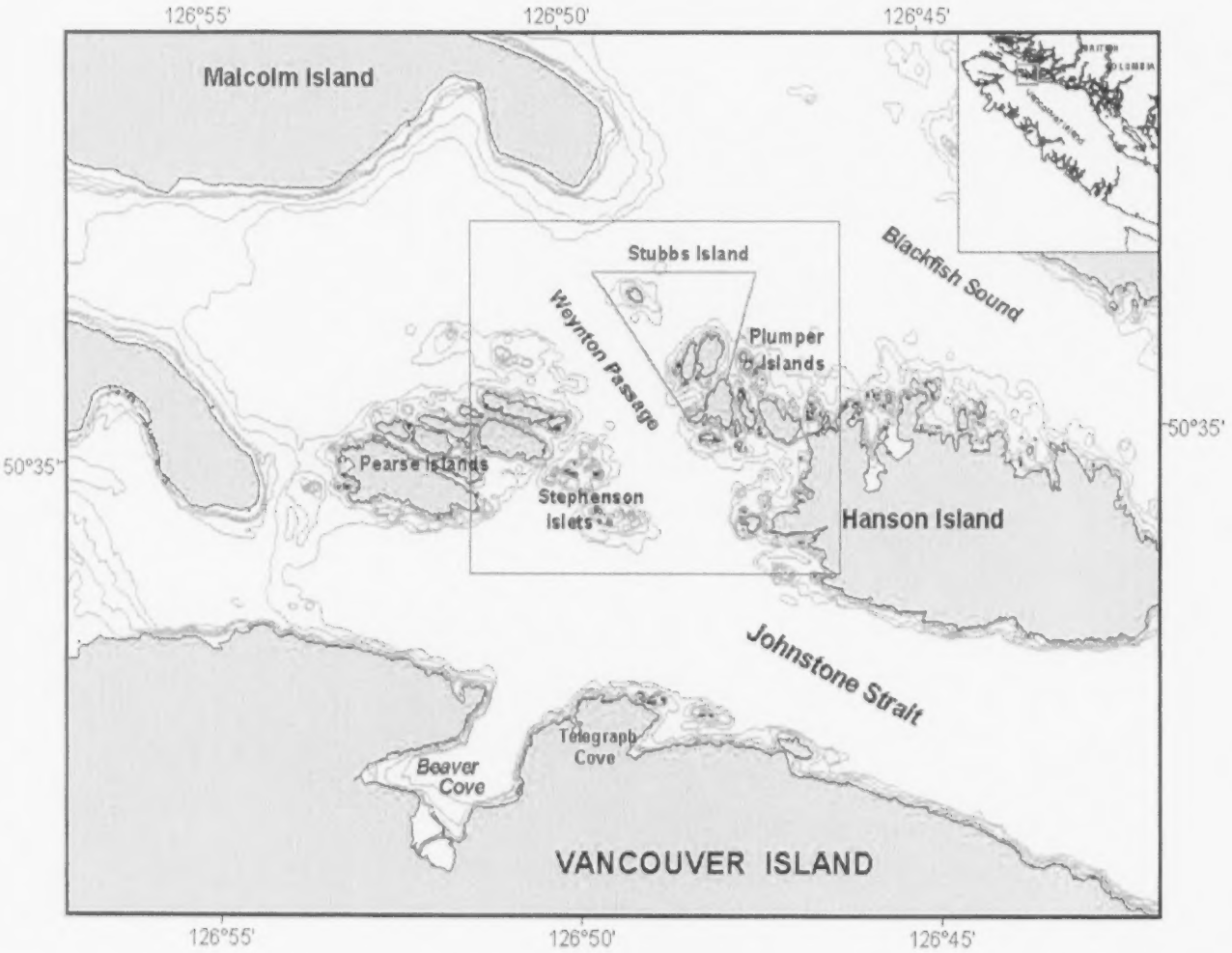

Fig. 1a. Site locations for the October 2008 and November 2010 green urchin surveys (Stephenson Islets, Stubbs Island and the Plumper Islands). The red border represents the boundaries of the research closure area. No commercial fishing may occur within these boundaries.

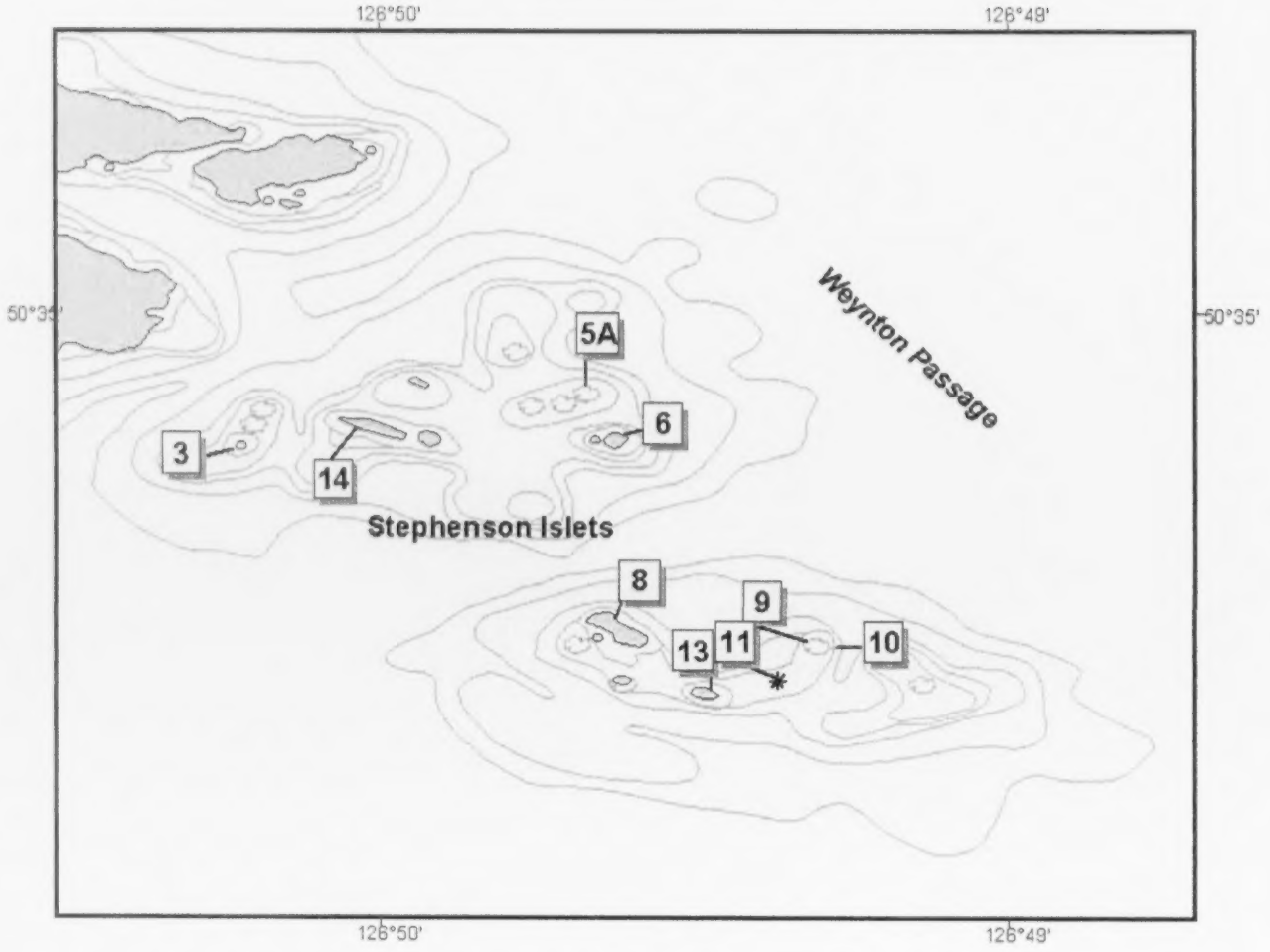

Fig. 1b. Transect locations (black lines) for the October 2008 (minus Transect 11) and November 2010 (minus Transect 10) green sea urchin surveys, Stephenson Islets.

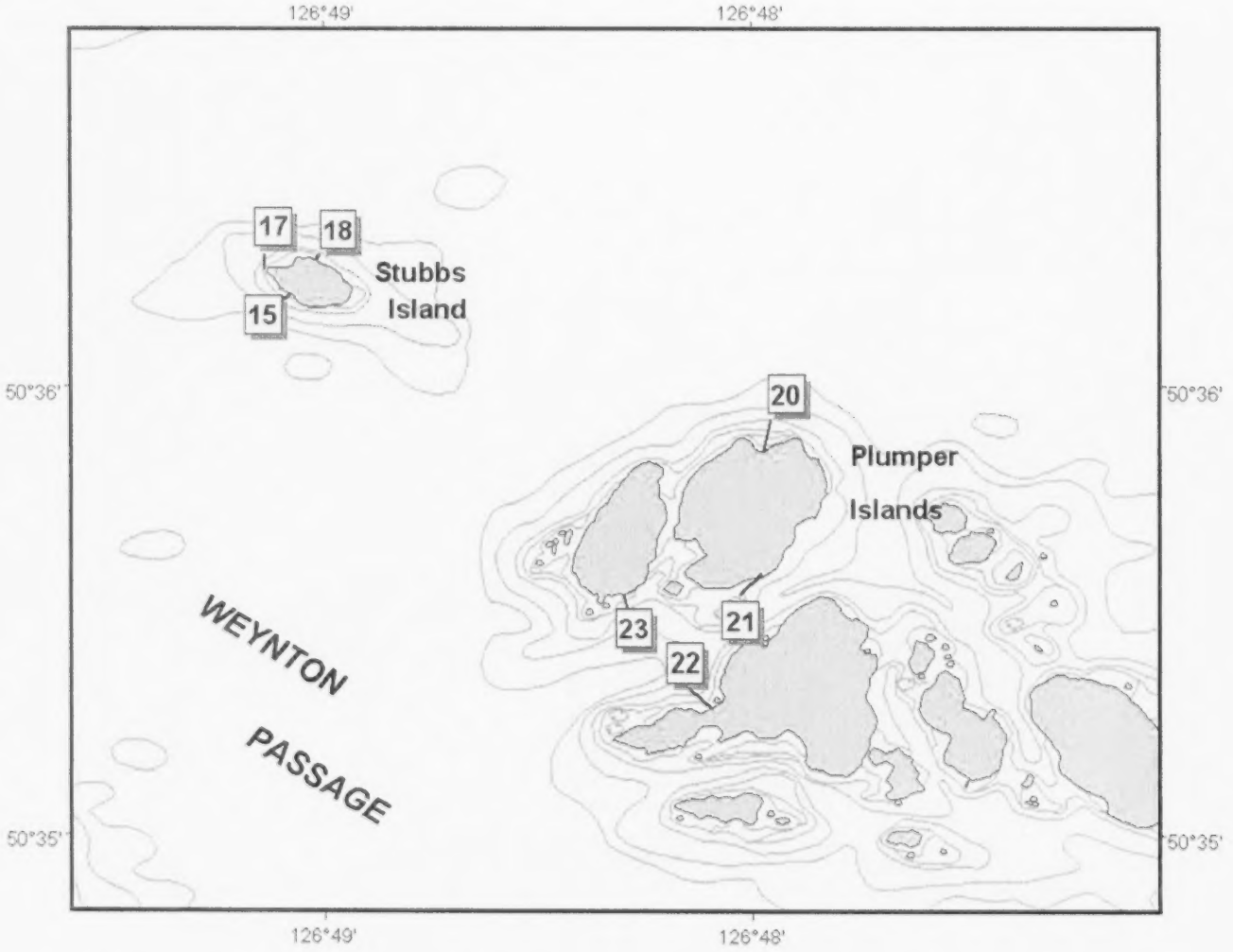

Fig. 1c. Transect locations (black lines) for the October 2008 and November 2010 green sea urchin surveys, Stubbs Island and the Plumper Islands.

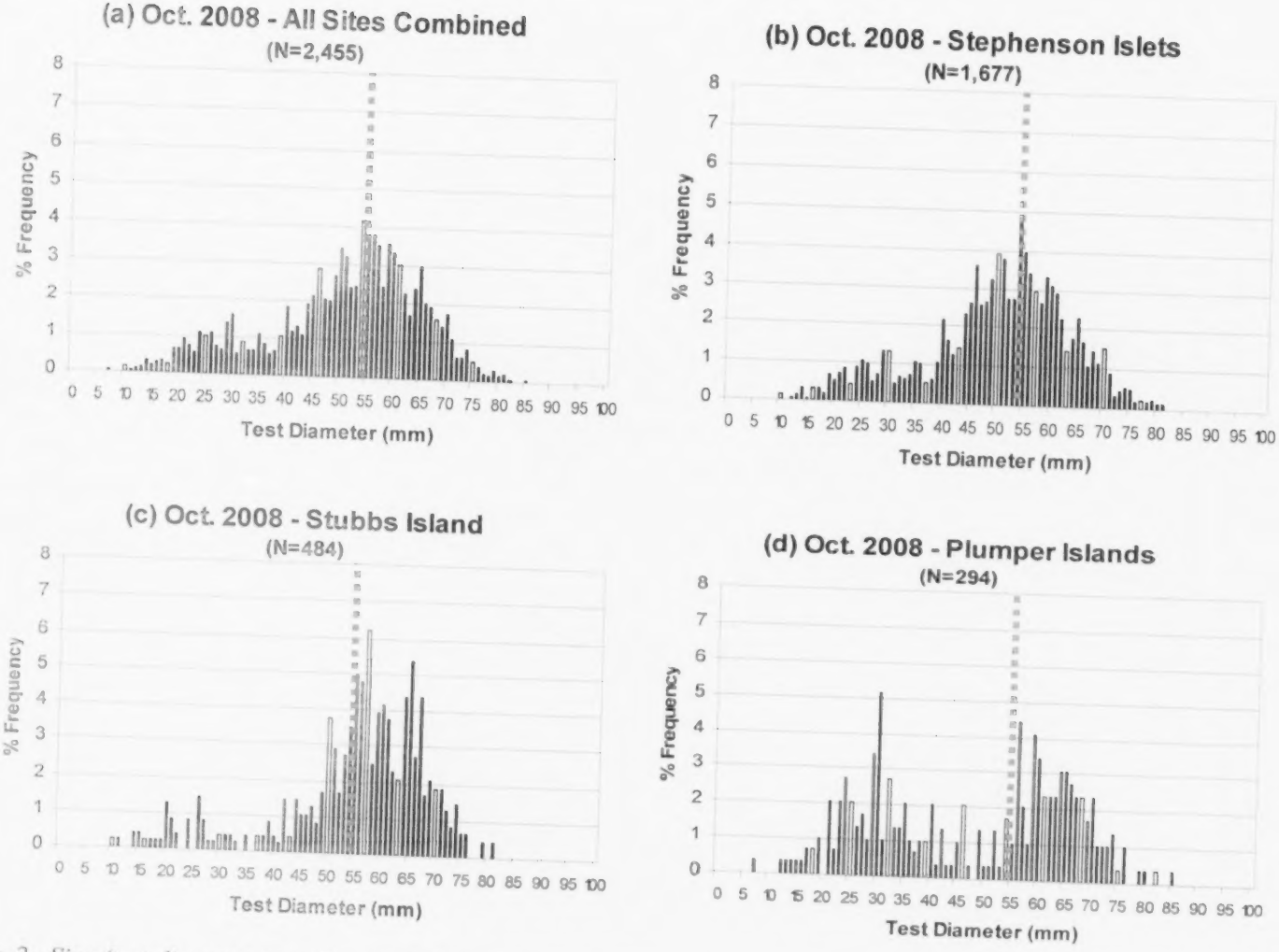

Fig. 2. Size (test diameter in millimeters) distributions of green sea urchins collected in October 2008 from (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. Note the fishery minimum size limit is 55 mm (red dashed line).

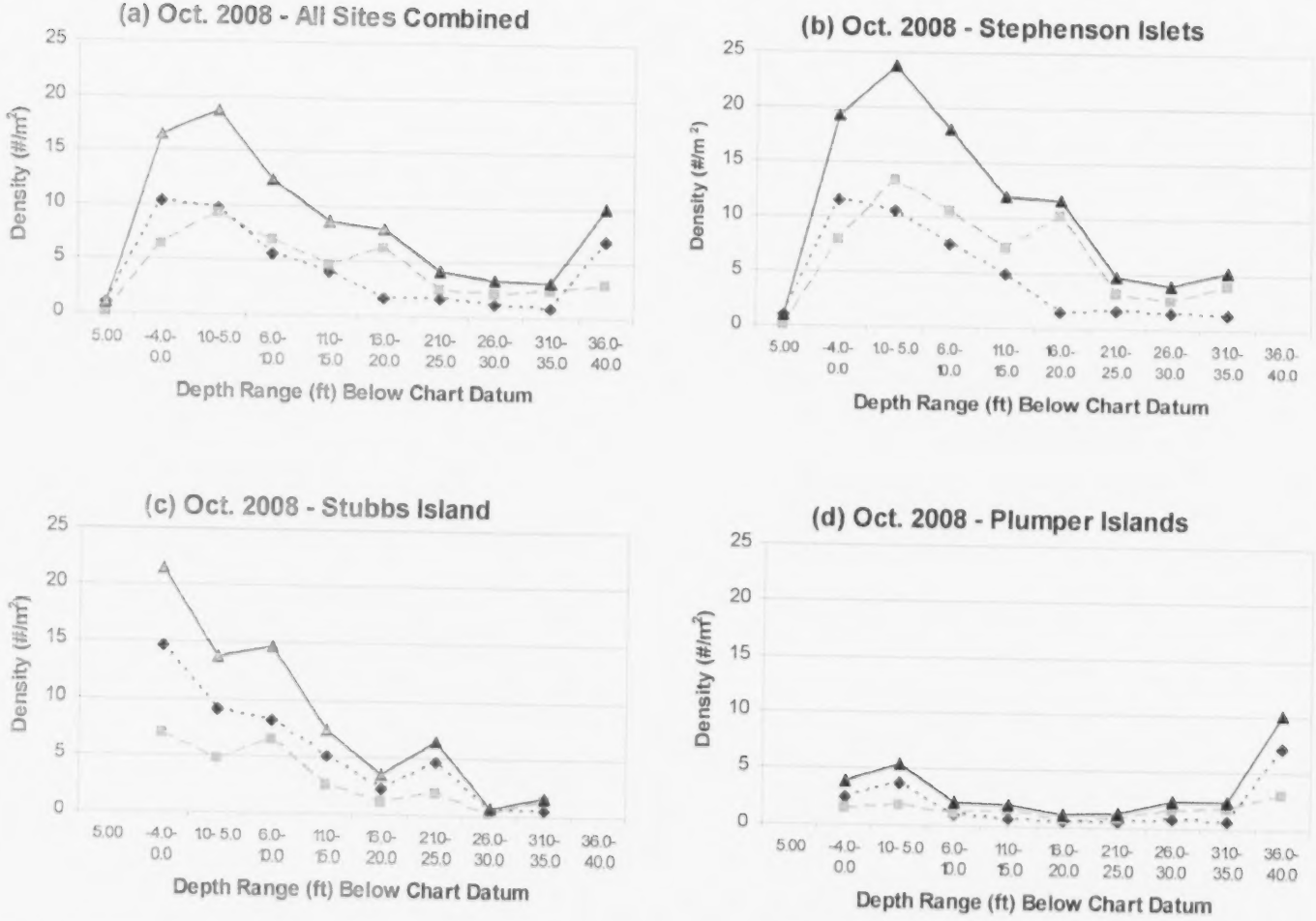

Fig. 3. October 2008 mean densities (number per square meter) of green sea urchins of all sizes (total = black triangles), legal size (blue diamonds), and sublegal size (red squares) by depth range (feet) below Chart Datum from: (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. Note that the density scale is consistent for all of the "density by depth" charts between both surveys.

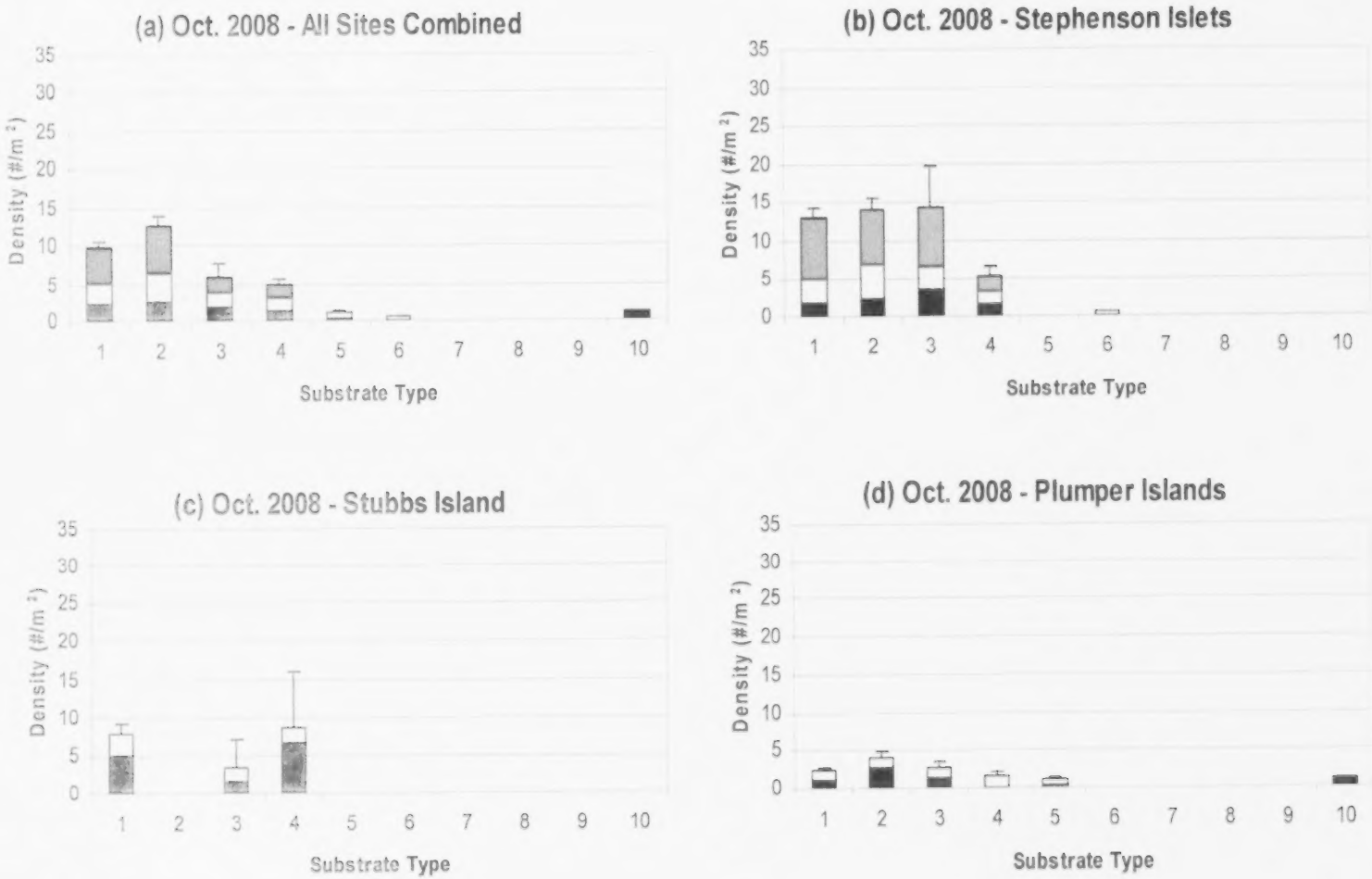

Fig. 4. October 2008 mean densities (number per square meter) of green sea urchins of legal size (black), sublegal size (white) and unknown size (blue), by main substrate type from: (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. See Tables 7a-d for the keys to the substrate codes. Unidentified substrates not displayed.

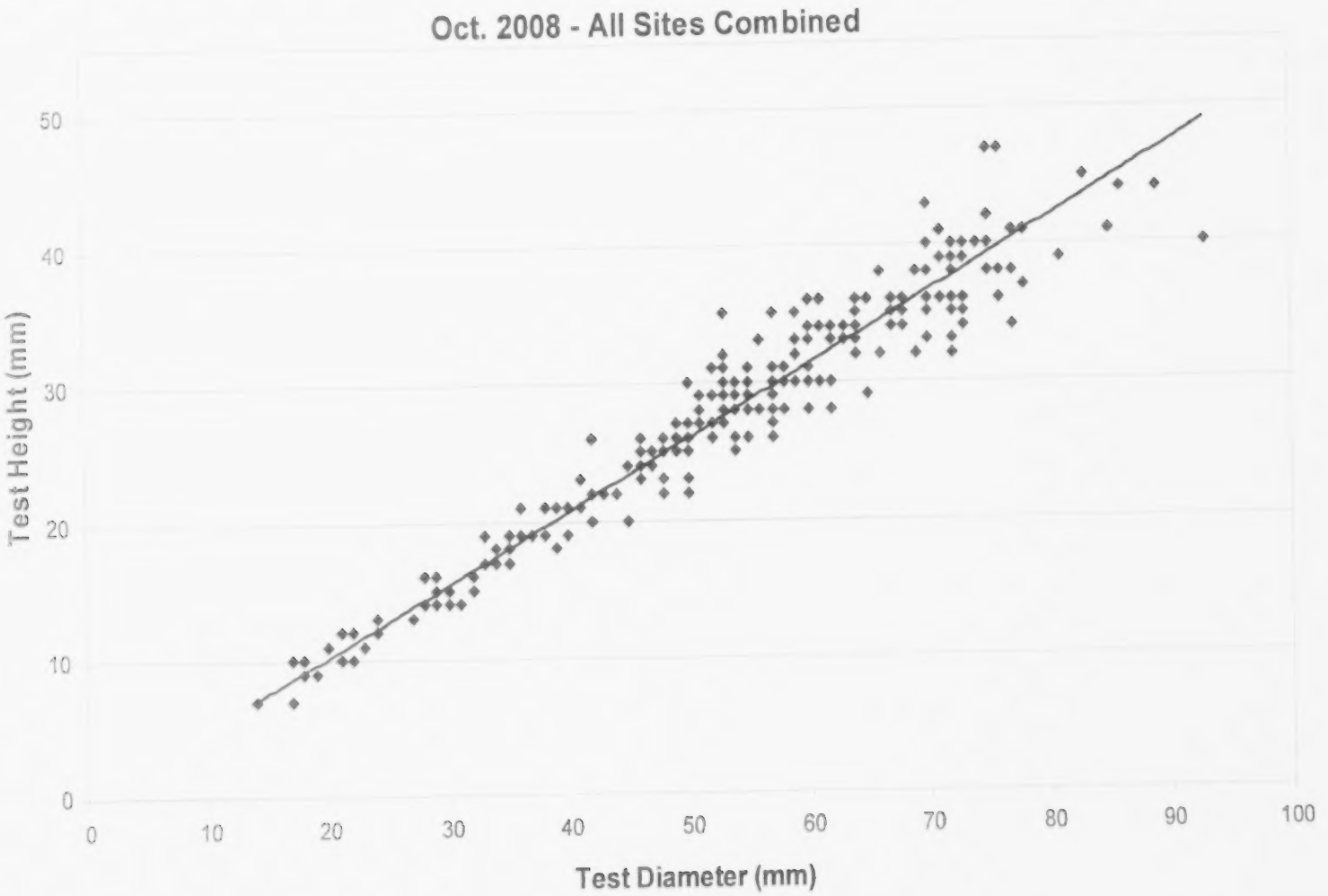

Fig. 5. Relationship between green sea urchin test diameter (TD, in millimeters) and test height (millimeters) in October 2008, for all sites combined: TEST HEIGHT *(mm)* $= 0.4755(TD^{1.0225})$, $R^2 = 0.9630$, $n=254$.

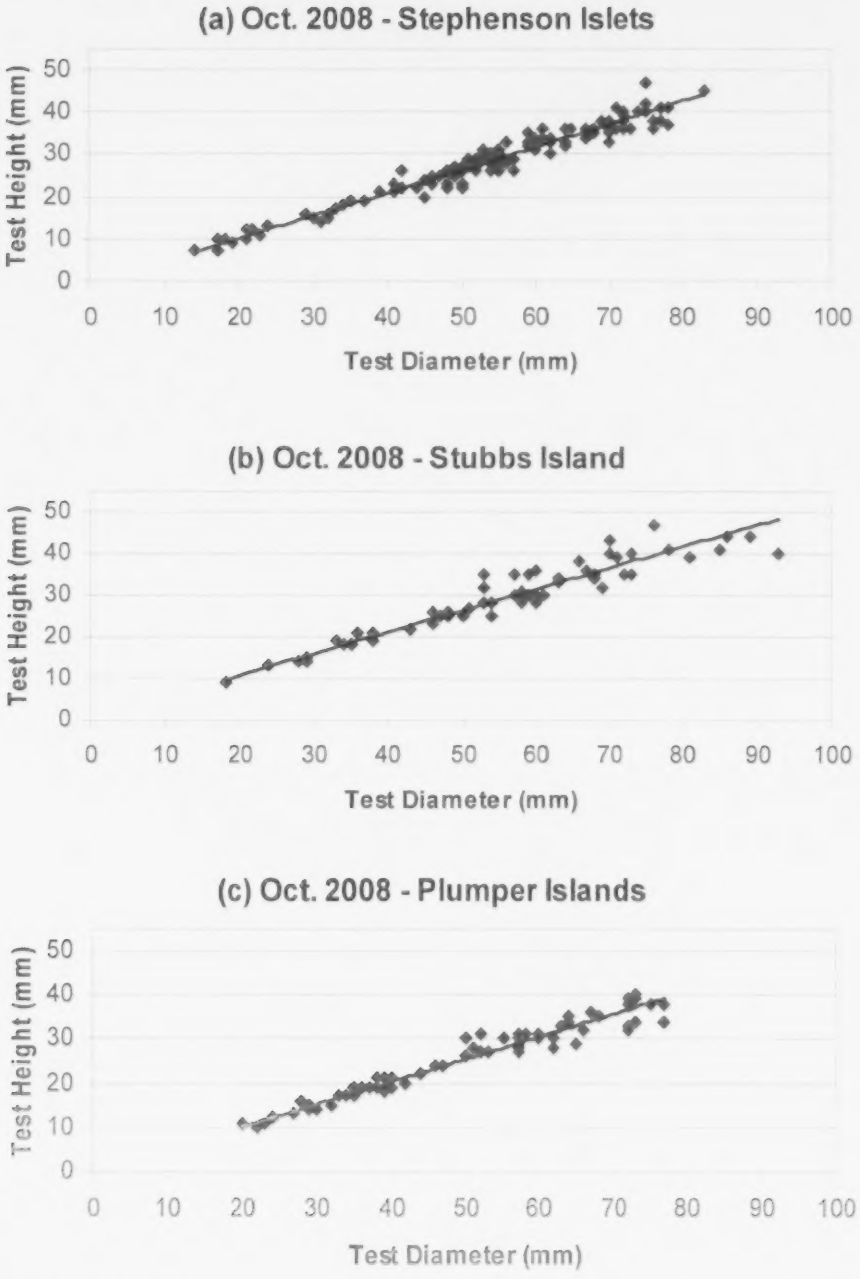
(a) Oct. 2008 - Stephenson Islets
Test Height (mm)
Test Diameter (mm)
(b) Oct. 2008 - Stubbs Island
Test Height (mm)
Test Diameter (mm)
(c) Oct. 2008 - Plumper Islands
Test Height (mm)
Test Diameter (mm)

Fig. 6. Relationships between green sea urchin test diameter (TD, in millimeters) and test height (millimeters) calculated in October 2008 for:
(a) Stephenson Islets (TEST HEIGHT (mm) = 0.4602(TD$^{1.0333}$), R^2 = 0.9682, n=122);
(b) Stubbs Island (TEST HEIGHT (mm) = 0.5757(TD$^{0.9772}$), R^2 = 0.9422, n=57);
(c) Plumper Islands (TEST HEIGHT (mm) = 0.4835(TD$^{1.012}$), R^2 = 0.9690, n=75).

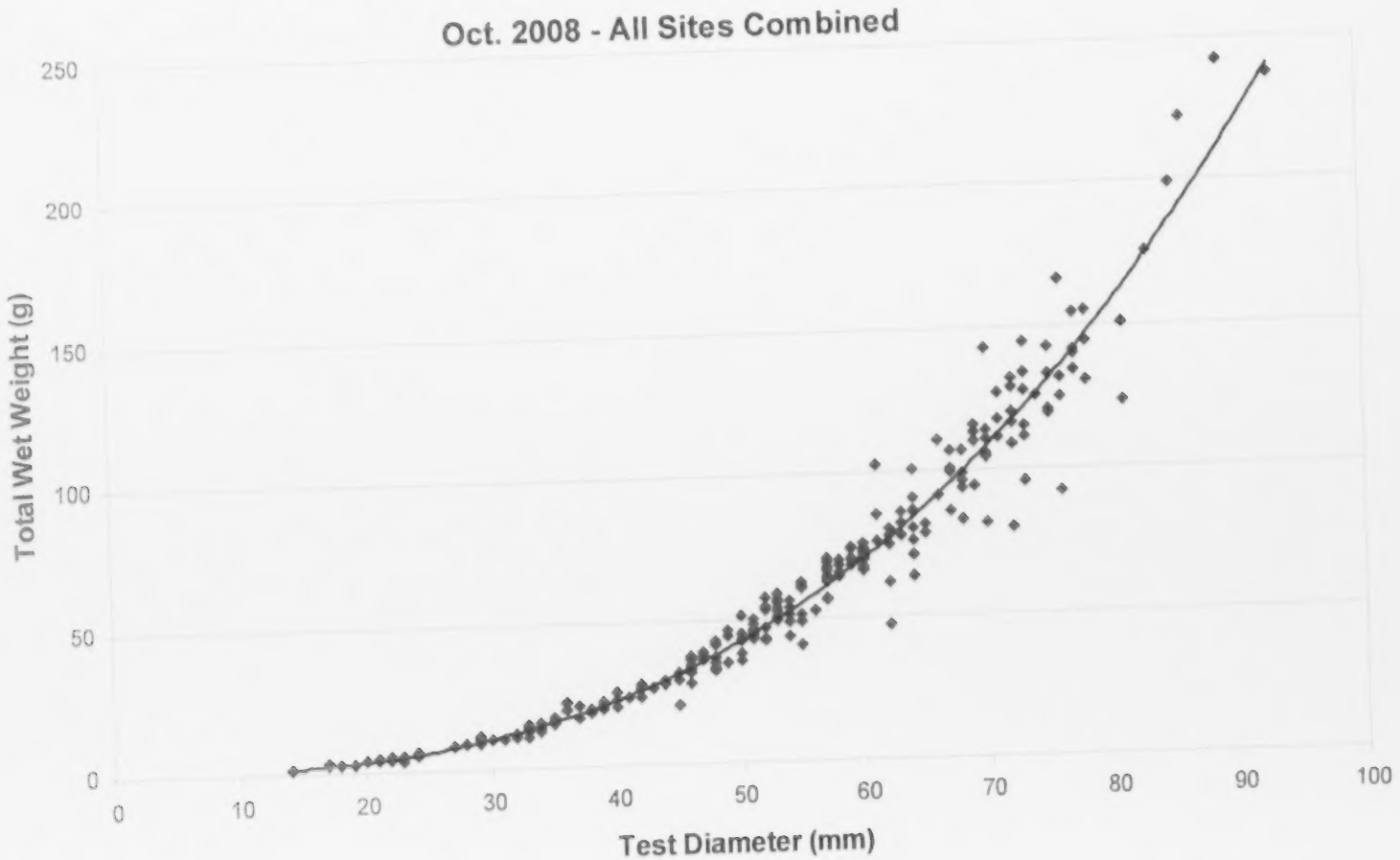

Fig. 7. Relationship between green sea urchin test diameter (TD, in millimeters) and total wet weight (grams) in October 2008, for all sites combined: TOTAL WET WEIGHT *(g) =* $0.0007(TD^{2.8002})$, $R^2 = 0.9868$, $n=254$.

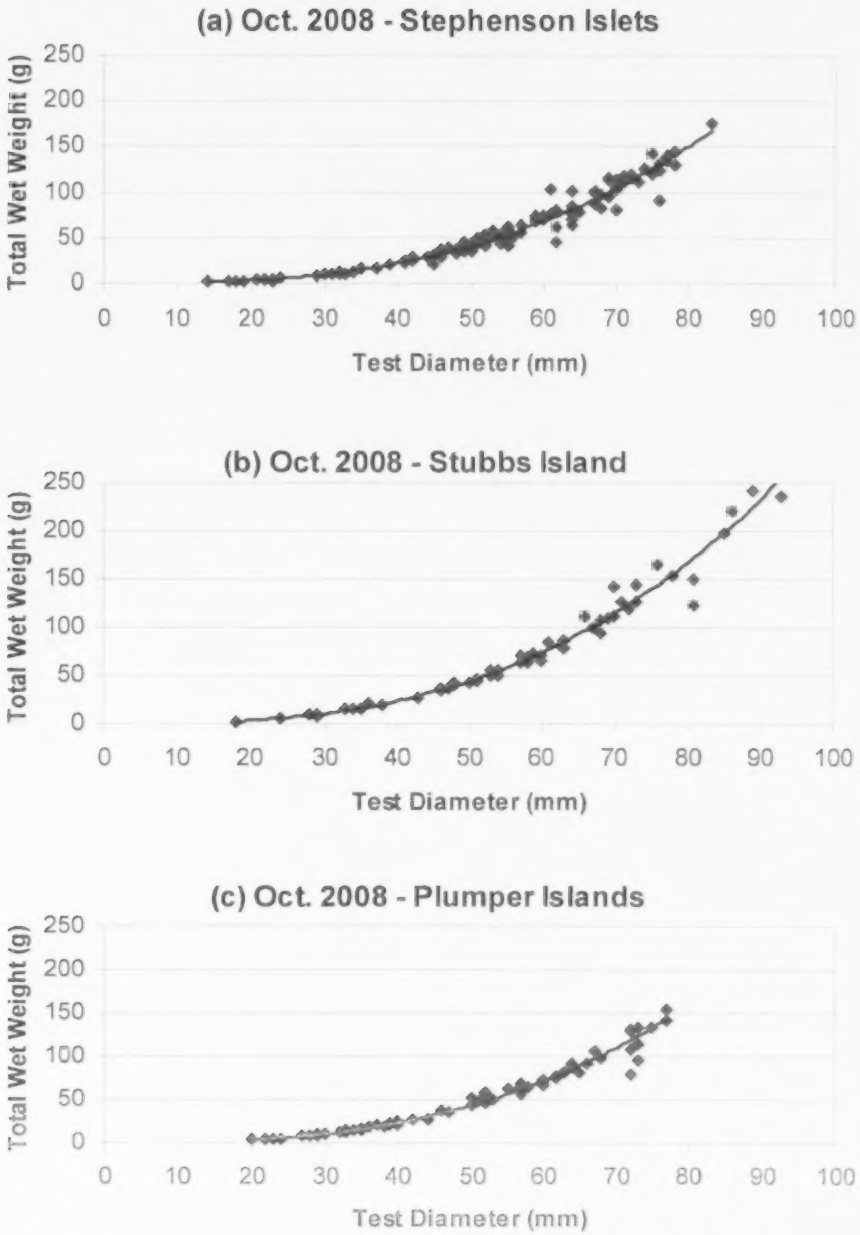

Fig. 8. Relationships between green sea urchin test diameter (TD, in millimeters) and total wet weight (grams) calculated in October 2008 for:
(a) Stephenson Islets (TOTAL WET WEIGHT (g) = $0.0007(TD^{2.7963})$, $R^2 = 0.9841$, n=122);
(b) Stubbs Island (TOTAL WET WEIGHT (g) = $0.0007(TD^{2.8269})$, $R^2 = 0.9918$, n=57);
(c) Plumper Islands (TOTAL WET WEIGHT (g) = $0.0008(TD^{2.7853})$, $R^2 = 0.9913$, n=75).

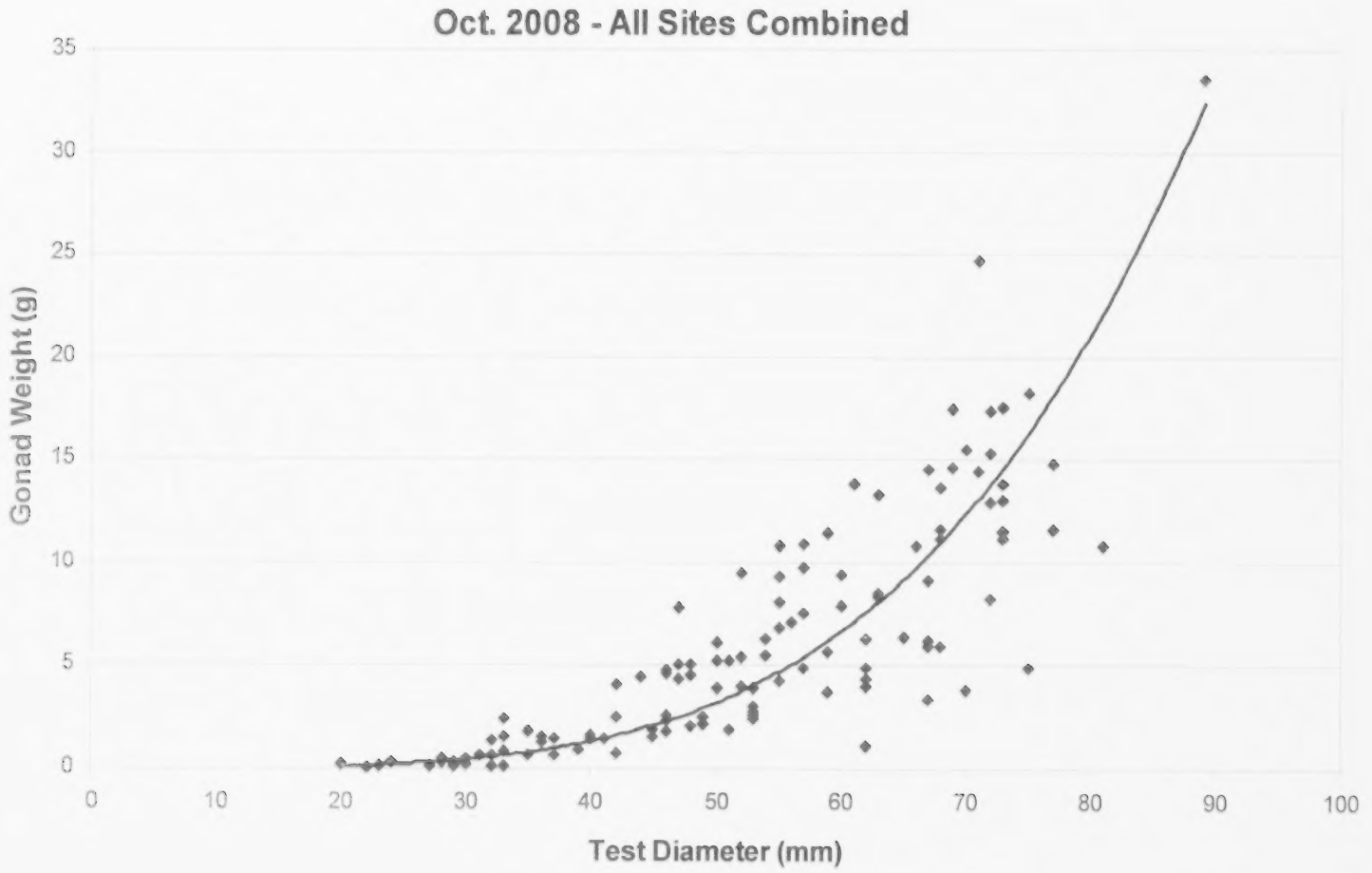

Fig. 9. Relationship between green sea urchin test diameter (TD, in millimeters) and gonad weight (grams) in October 2008, calculated from all sites combined: $\text{GONAD WEIGHT (g)} = 5 \times 10^{-7} (TD^{4.0255})$; $R^2 = 0.8303$, $n = 124$.

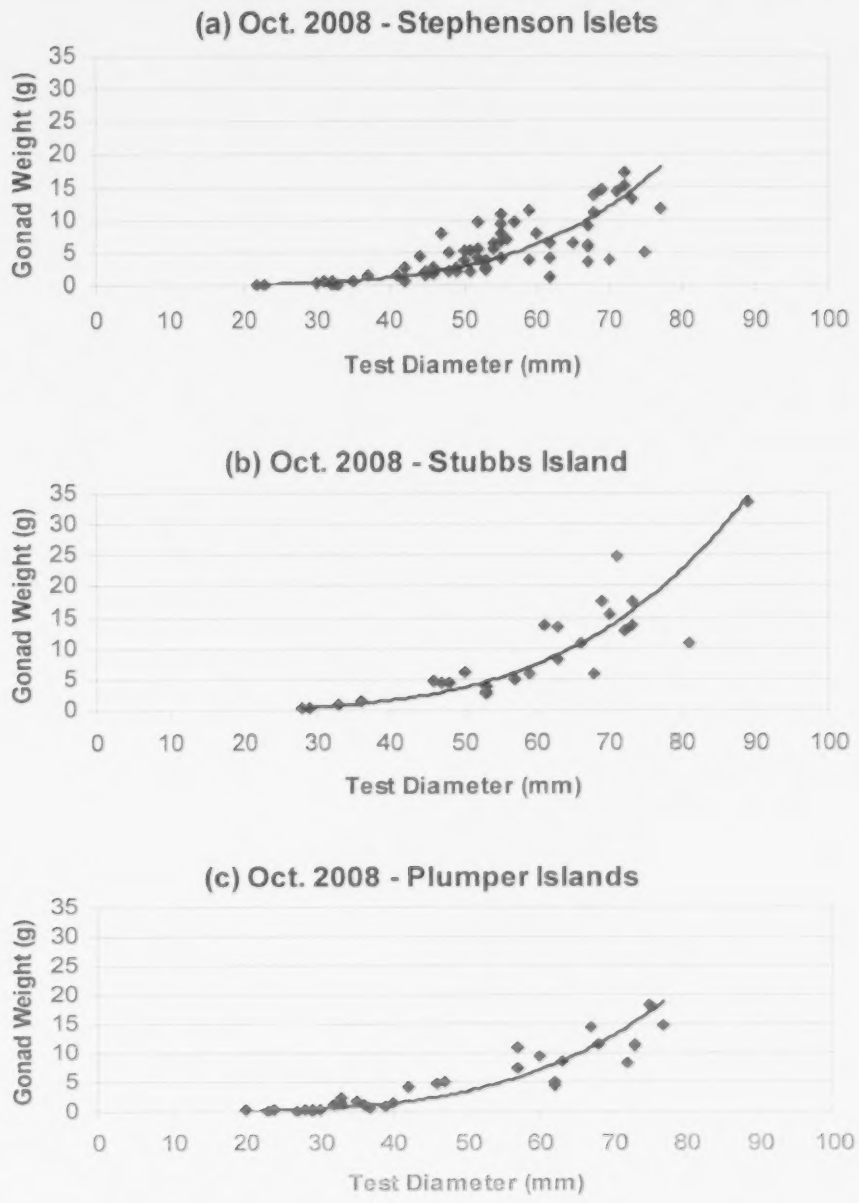
(a) Oct. 2008 - Stephenson Islets
Gonad Weight (g)
Test Diameter (mm)
(b) Oct. 2008 - Stubbs Island
Gonad Weight (g)
Test Diameter (mm)
(c) Oct. 2008 - Plumper Islands
Gonad Weight (g)
Test Diameter (mm)

Fig. 10. Relationships between green sea urchin test diameter (TD, in millimeters) and gonad weight (grams) calculated in October 2008 for:
(a) Stephenson Islets (GONAD WEIGHT (g) = 2 x 10^{-7} ($TD^{4.2602}$), R^2 = 0.7718, n=63);
(b) Stubbs Island (GONAD WEIGHT (g) = 9 x 10^{-7} ($TD^{3.8989}$), R^2 = 0.8885, n=26);
(c) Plumper Islands (GONAD WEIGHT (g) = 7 x 10^{-7} ($TD^{3.9408}$), R^2 = 0.8558, n=35).

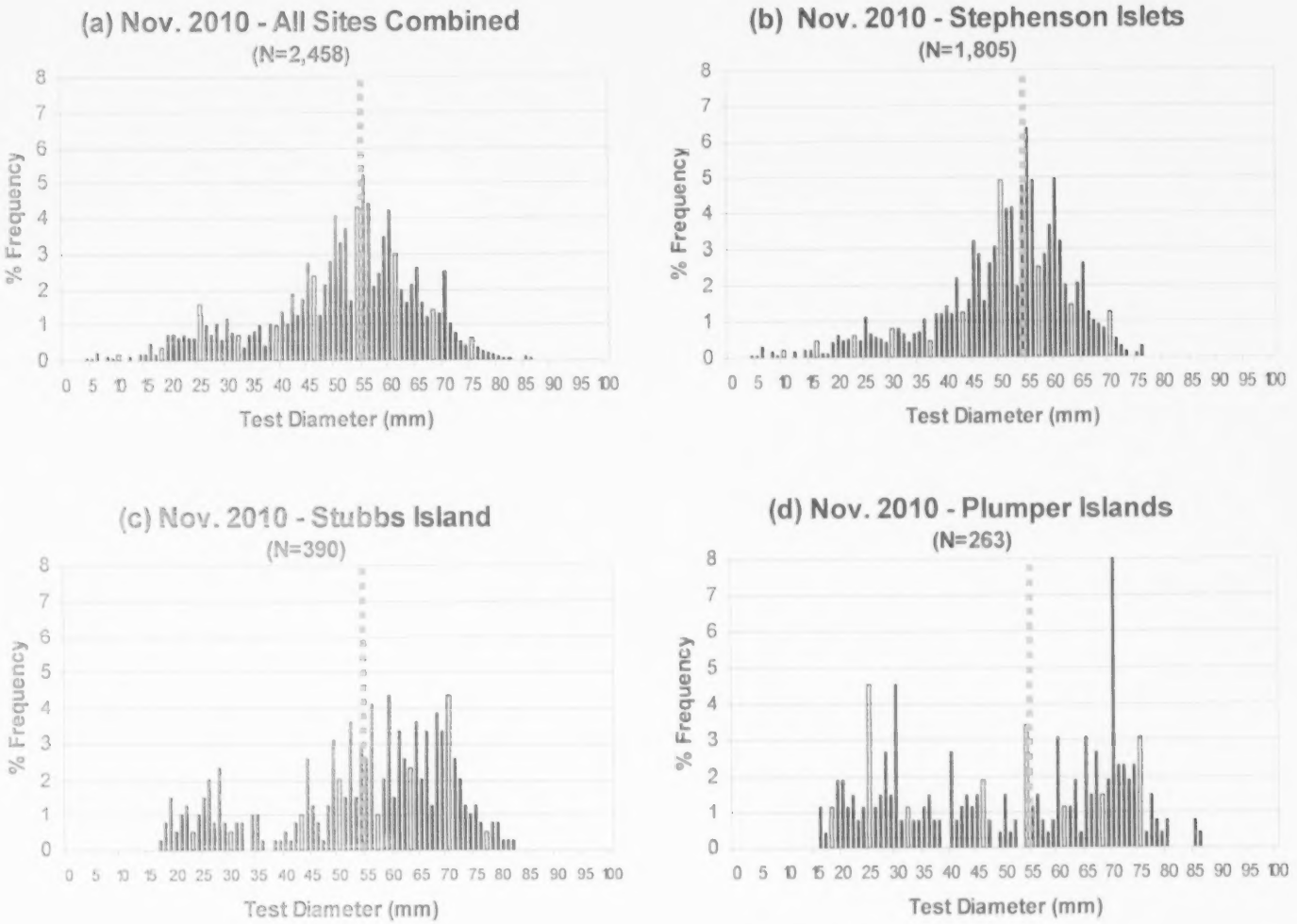

Fig. 11. Size (test diameter in millimeters) distributions of green sea urchins collected in November 2010 from (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. Note the fishery minimum size limit is 55 mm (red dashed line).

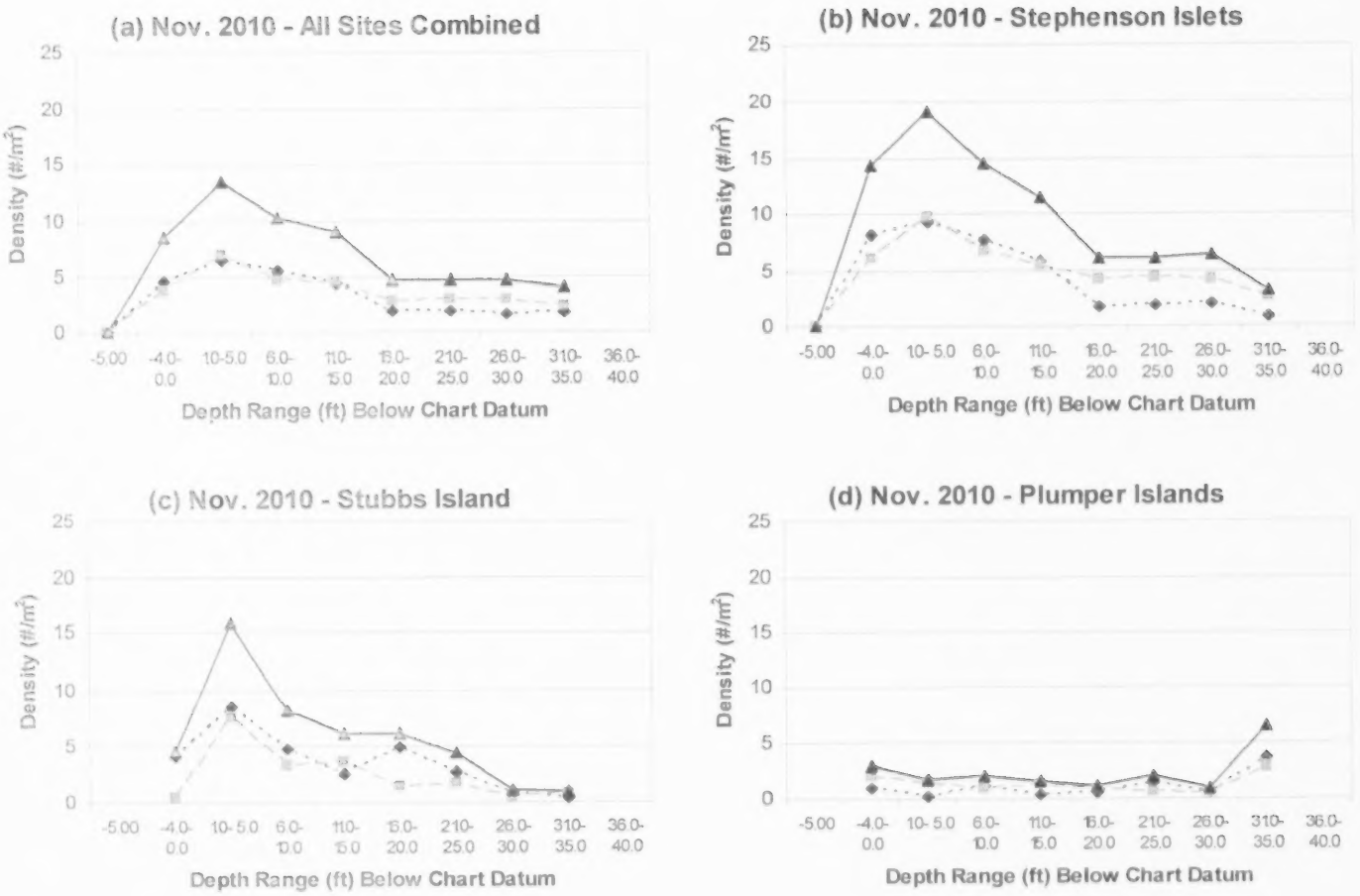

Fig. 12. November 2010 mean densities (number per square meter) of green sea urchins of all sizes (total = black triangles), legal size (blue diamonds), and sublegal size (red squares) by depth range (feet) below Chart Datum from: (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. Note that the density scale is consistent for all of the "density by depth" charts between both surveys.

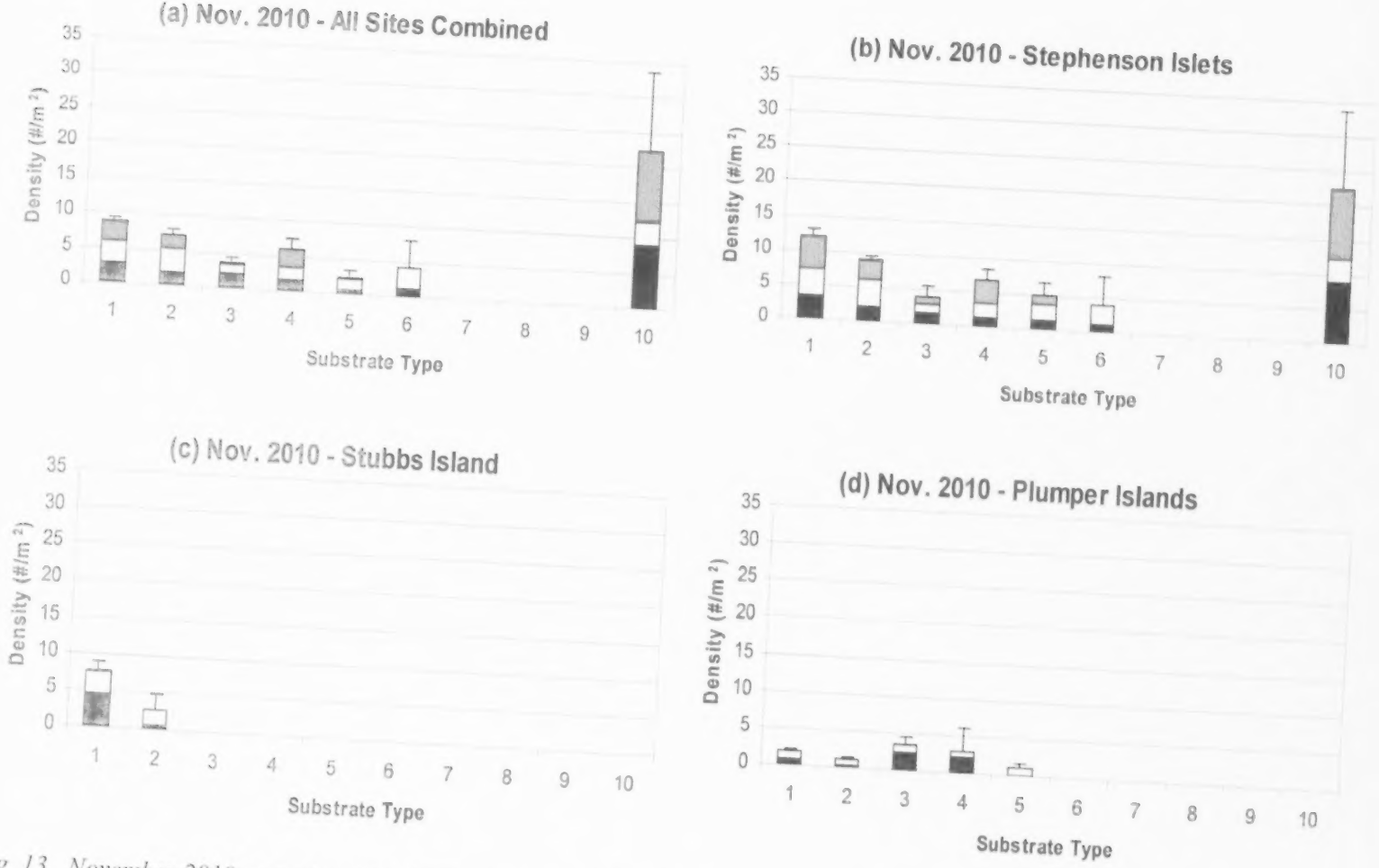

Fig. 13. November 2010 mean densities (number per square meter) of green sea urchins of legal size (black), sublegal size (white) and unknown size (blue), by main substrate type from: (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. See Tables 16a-d for the keys to the substrate codes. Unidentified substrates not displayed.

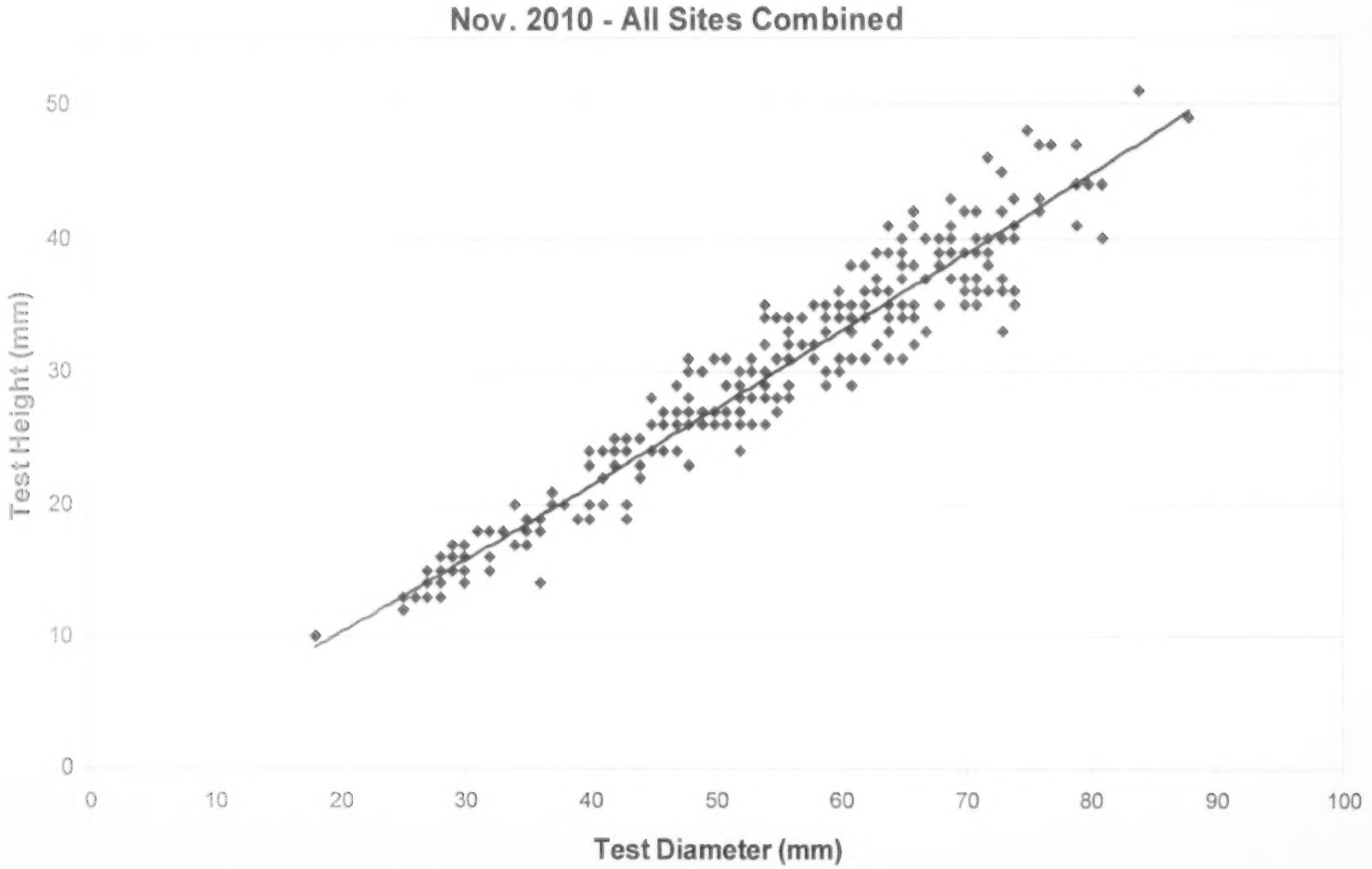

Fig. 14. Relationship between green sea urchin test diameter (TD, in millimeters) and test height (millimeters) in November 2010, for all sites combined: TEST HEIGHT *(mm)* $= 0.4281(TD^{1.0608})$, $R^2 = 0.9390$, $n=277$.

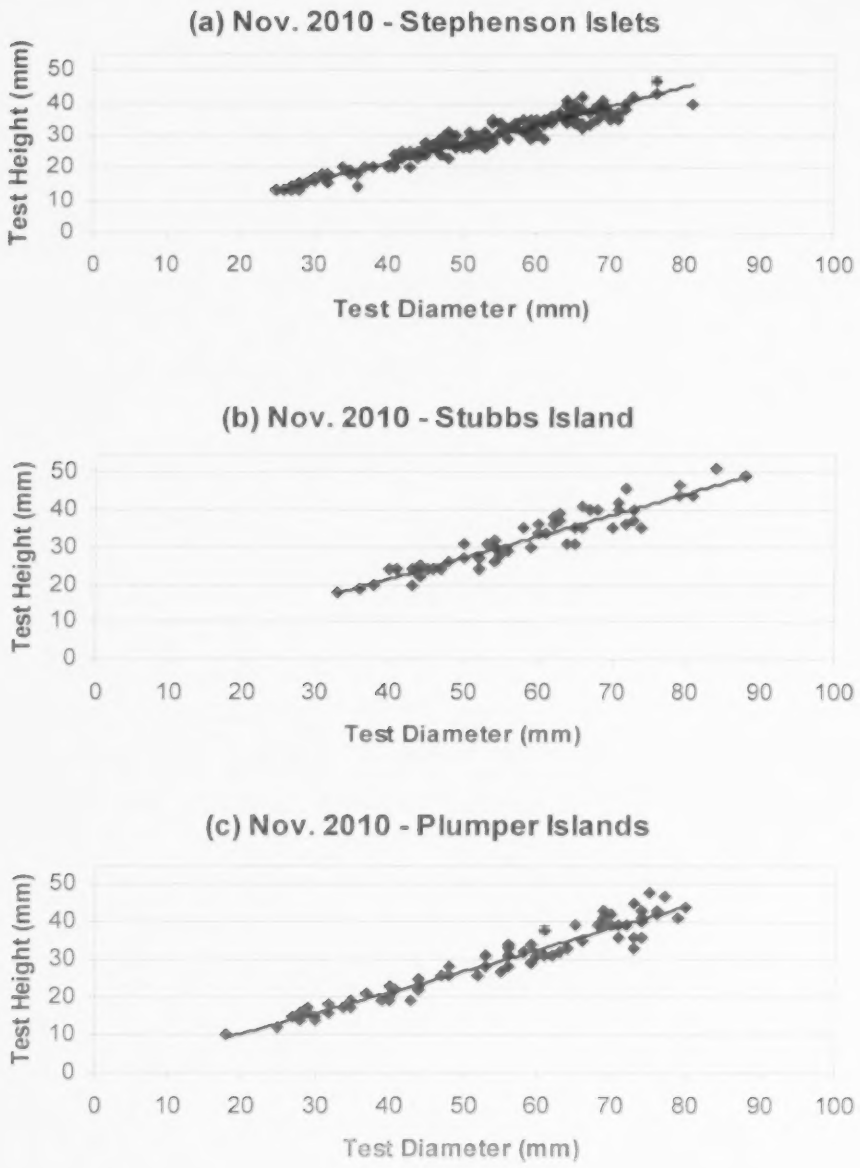
(a) Nov. 2010 - Stephenson Islets
Test Height (mm)
Test Diameter (mm)
(b) Nov. 2010 - Stubbs Island
Test Height (mm)
Test Diameter (mm)
(c) Nov. 2010 - Plumper Islands
Test Height (mm)
Test Diameter (mm)

Fig. 15. Relationships between green sea urchin test diameter (TD, in millimeters) and test height (millimeters) calculated in November 2010 for:
(a) Stephenson Islets (TEST HEIGHT (mm) = $0.4190(TD^{1.0679})$, $R^2 = 0.9346$, n=149);
(b) Stubbs Island (TEST HEIGHT (mm) = $0.4533(TD^{1.0462})$, $R^2 = 0.8886$, n=56);
(c) Plumper Islands (TEST HEIGHT (mm) = $0.4264(TD^{1.0590})$, $R^2 = 0.9579$, n=72).

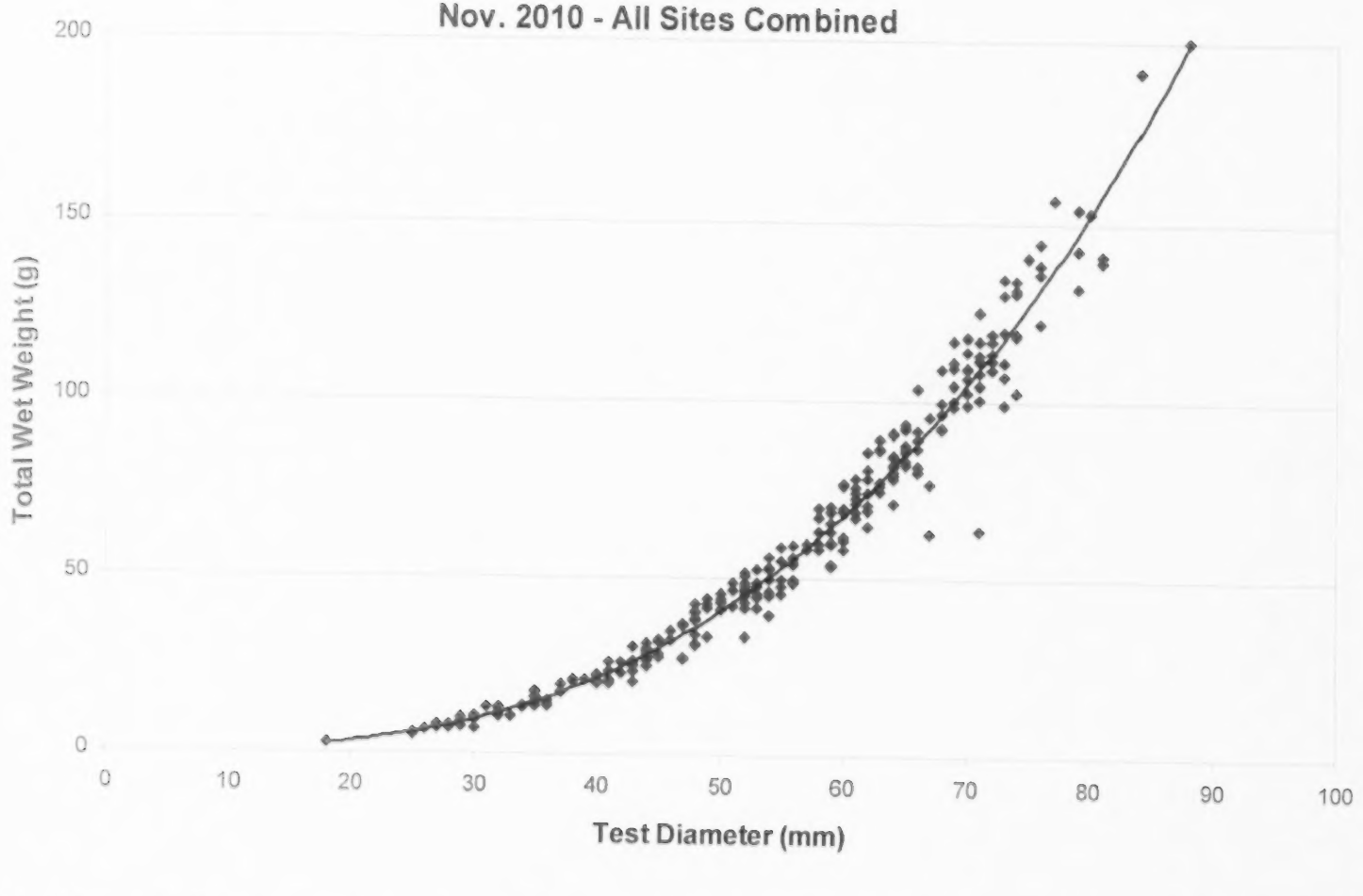

Fig. 16. Relationship between green sea urchin test diameter (TD, in millimeters) and total wet weight (grams) in November 2010, for all sites combined: TOTAL WET WEIGHT *(g) = 0.0006(TD$^{2.8303}$), R^2 = 0.9856, n=277.*

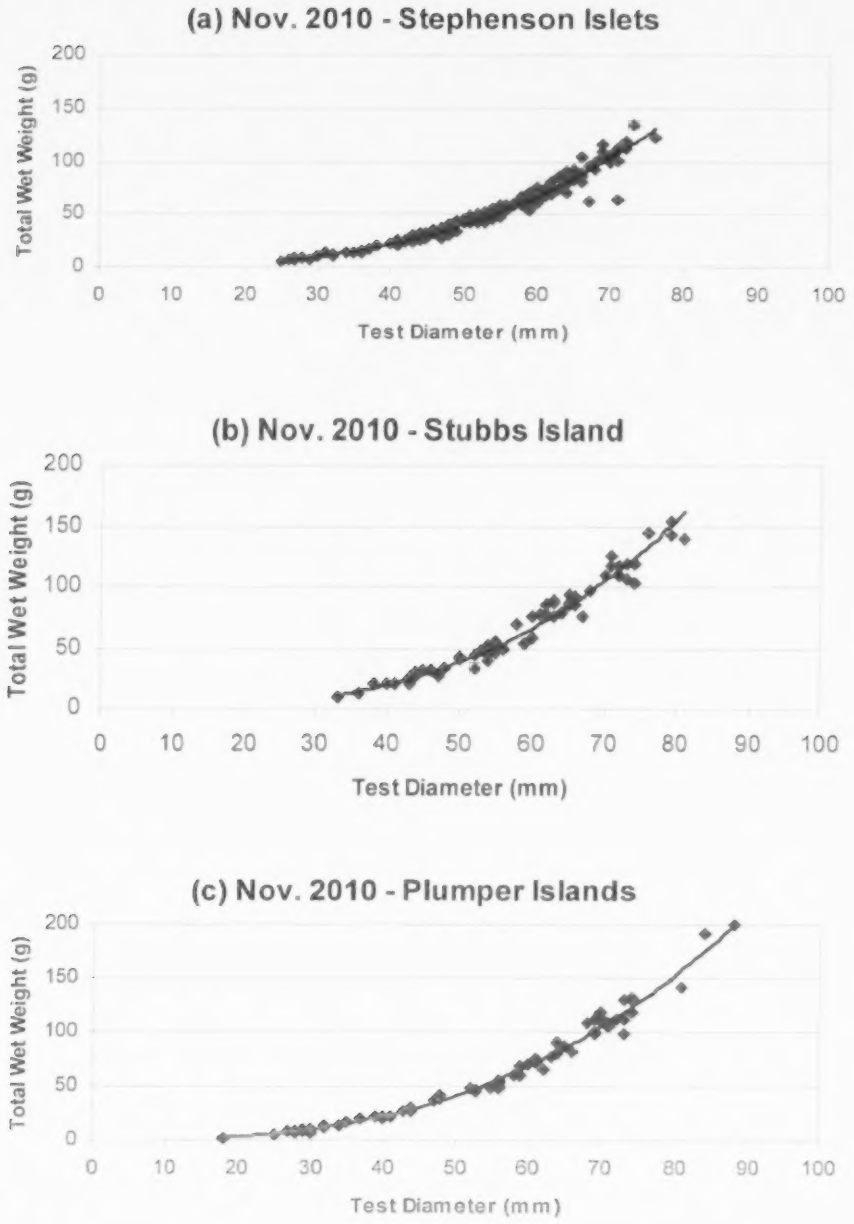

Fig. 17. Relationships between green sea urchin test diameter (TD, in millimeters) and total wet weight (grams) calculated in November 2010 for:
(a) Stephenson Islets (TOTAL WET WEIGHT (g) = 0.0007(TD$^{2.8110}$), R^2 = 0.9826, n=149);
(b) Stubbs Island (TOTAL WET WEIGHT (g) = 0.0003(TD$^{2.9772}$), R^2 = 0.9728, n=56);
(c) Plumper Islands (TOTAL WET WEIGHT (g) = 0.0007(TD$^{2.8161}$), R^2 = 0.9928, n=72). .

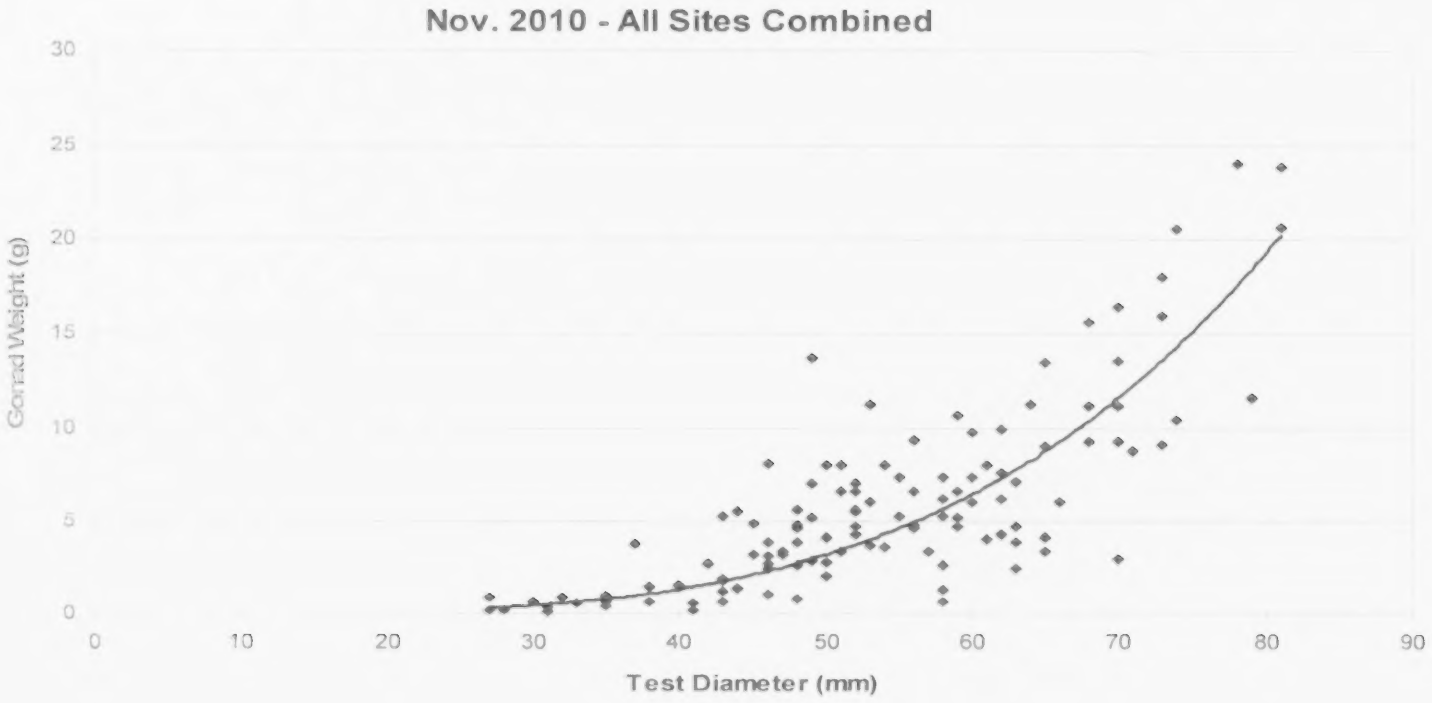

Fig. 18. Relationship between green sea urchin test diameter (TD, in millimeters) and gonad weight (grams) in November 2010, calculated from all sites combined: GONAD WEIGHT *(g) = 1 x 10^{-6}($TD^{3.8165}$); R^2 = 0.6822, n = 122.*

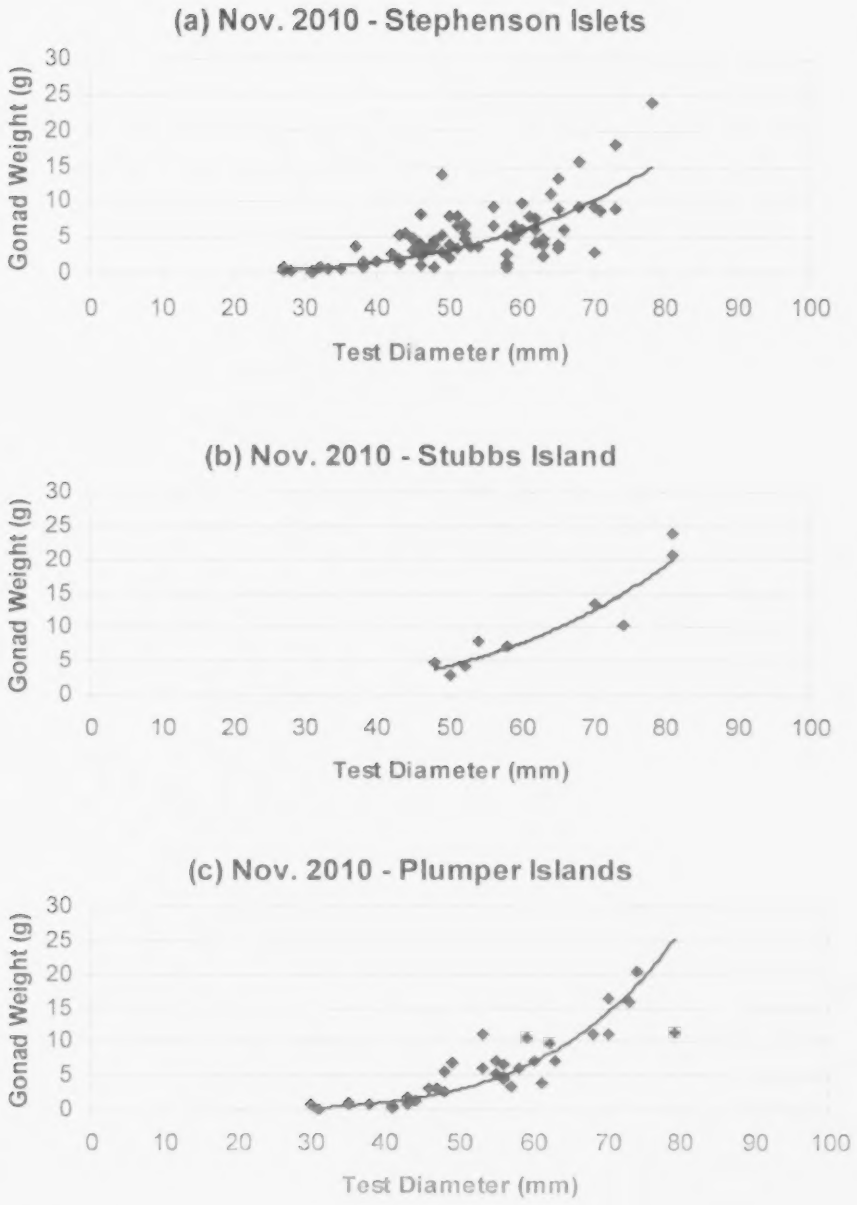
(a) Nov. 2010 - Stephenson Islets
Gonad Weight (g)
Test Diameter (mm)
(b) Nov. 2010 - Stubbs Island
Gonad Weight (g)
Test Diameter (mm)
(c) Nov. 2010 - Plumper Islands
Gonad Weight (g)
Test Diameter (mm)

Fig. 19. Relationships between green sea urchin test diameter (TD, in millimeters) and gonad weight (grams) calculated in November 2010 for:
(a) Stephenson Islets (GONAD WEIGHT (g) = 4 x 10^{-6} ($TD^{3.4536}$), R^2 = 0.6122, n=78);
(b) Stubbs Island (GONAD WEIGHT (g) = 2 x 10^{-5} ($TD^{3.1739}$), R^2 = 0.8622, n=9);
(c) Plumper Islands (GONAD WEIGHT (g) = 4 x 10^{-8} ($TD^{4.6280}$), R^2 = 0.7863, n=35).